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JOURNAL

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American Society of Agronomy

VOL. 19 JANUARY, 1927 No. 1

SYMPOSIUM ON "PUBLICATION OF THE RESULTS OF AGRONOMIC RESEARCH"

Leader: R. W. Thatcher, Director of Experiment Stations, Cornell University

1. "Should the Results of Agronomic Research be Published in Bulletins, or in Scientific Journals, or Both?" R. W. Thatcher, New York Agricultural Experiment Stations

2. "The Technical Bulletin as the Writer Sees It." C. R. Ball, Bureau of Plant Industry, U. S. Department of Agriculture

3. "Characteristics of a Good Journal Article." M. C. Merrill, Editorial Office, U. S. Department of Agriculture

4. "Methods of Graphic Representation of Experimental Data." J. D. Luckett, New York State Agricultural Experiment Station

5. "Making Photographs for Illustration in Published Articles." C. H. Hanson, Office of Cooperative Extension Work, U. S. Department of Agriculture

6. "Popular Presentation of the Results of Agronomic Research." J. F. Cox, Michigan State College

1. SHOULD THE RESULTS OF AGRONOMIC RESEARCH BE PUBLISHED IN BULLETINS, OR IN SCIENTIFIC JOURNALS, OR BOTH?[1]

R. W. THATCHER[2]

It has been the hope of the leader that this symposium will serve two purposes: One, that it will afford an interesting program to those who are in attendance at this session of the annual meeting; the other, that when the papers presented here are published in the JOURNAL of the Society, they will both set certain standards and serve as guides for authors in their preparation of manuscripts for future publication.

In outlining the program for this symposium, it seemed to be logical to set down the question which is the topic for this paper as the first phase of the subject to be discussed. Then, since the writer has served as the Director of four different experiment stations and is now serving as the Editor of the JOURNAL of this Society, it seemed that he might be in an appropriate position to discuss both sides of the question. Hence, it was determined to assign this topic to the leader of the symposium to present as its opening paper. This paper has been made a brief one, with the deliberate intention to permit more time to be available for subsequent discussions of more technical phases of the general subject of the symposium.

The question "Should the Results of Agronomic Research Be Published in Bulletins, or in Scientific Journals, or Both?" is not simply a query which can be answered by a positive affirmative statement based upon clearly evident facts. It is rather a topic for discussion, in which each of the several alternatives presented has its advantages and its disadvantages to be considered.

The question is based on the assumption that a large proportion, at least, of the agronomic research of the country is being done at those institutions, like the state experiment stations and the United States Department of Agriculture, which have regular series of bulletins in which the results of their research may be published. There are, of course, notable exceptions to this general rule; but to these the second alternative of publication in scientific journals will usually apply.

Again, it should be understood that this particular discussion deals only with the publication of the results of agronomic research in technical form, whereby the technic of the investigation and the data gathered may be discussed in support of and studied in connection with conclusions which are presented. There are many other avenues of publication for popular presentations of the results of research as they are to be applied in practice, including the agricultural press, popular lectures, demonstrations, news letters, etc., etc. Some of these latter will be discussed in the last paper on this program; but the earlier numbers of the program are intended to deal only with the problems of publication of the results of research in technical form.

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[1] Paper read as a part of the symposium on "Publication of Results of Agronomic Research" at the meeting of the Society held in Washington, D. C., November 18, 1926.

[2] Director of Experiment Stations, Cornell University, Geneva, N. Y.

The history of the publication of bulletins of the United States Department of Agriculture and of the state experiment stations shows that they have gone through many changes in purpose and character. Undoubtedly, they were first established partly to provide an avenue for publication of the results of original research at the institutions themselves and partly as intended additions to the meager supply of general literature concerning agricultural science and practice which existed at that time. In their early days, the laws which authorized these publications generally specified that they were to be distributed to newspapers, etc., and only incidentally provided for distribution directly to farmer users of the information presented. An examination of these earlier bulletins indicates, however, that while there were occasional examples of technical presentation of the results of scientific study, many of them apparently were prepared for the purpose of giving general information which the author possessed and which would be of use presumably in determining agricultural practices. There was a very common impression at that time that the bulletins of an experiment station were intended chiefly for farmer readers. There are, of course, many exceptions to any general statement of this kind; but it seems to the writer to be a fair characterization of the purpose and type of most of the earlier bulletins.

In fact, there are those who now regret that bulletins of the state experiment stations have changed in character in recent years and that the stations are now seriously out of touch with the final users of the results of their researches.

This change has come about, as every one knows, as a result of the development of the agricultural extension service, with its many methods of teaching concerning farm practices, including its own series of bulletins for this purpose.

In the interim during which this evolution was taking place, most of the institutions adopted the plan of dividing their publications into two or more series, one of which was designated by some title such as "technical bulletins," or "research bulletins," to indicate that they were intended to convey information of technical character which is of interest chiefly to other scientific workers. Another series of "general" or non-technical, sometimes even called "popular," bulletins is usually maintained by each station; while the United States Department of Agriculture issues the well-known "Farmers Bulletins," for the publication of either original or compiled results of investigations in a form suitable for reading or study by the ultimate user in actual practice of the material which is presented.

Partly for reasons of economy and partly because the widespread promiscuous distribution of free bulletins to recipients who have little or no interest in them has tended to bring them into light esteem if not actual disrepute, the earlier practice of building up large mailing lists for bulletins has now been largely done away with. Some stations maintain no mailing lists at all, and send their bulletins only in response to individual requests for them. Thus, it happens that it is almost an impossibility for an agronomist to be sure now that he will receive automatically anything like a complete file of the bulletins of the state experiment stations which report results of agronomic research.

The bulletins of the stations and Department are very satisfactorily abstracted in the *Experiment Station Record* and it is possible for an agronomist who faithfully studies each issue of the *Record* and follows this up by writing for the original paper in each case to accumulate a very complete file of station and Department agronomy bulletins in this way. But the process of sorting out agronomic bulletins from the many other publications of these institutions dealing with other phases of agricultural science and practice is a long and tedious one and likely to be only indifferently well done by most agronomists. When one adds to this difficulty the necessary expense in time and money required to apply personally for original copies of the desired bulletins, the net result comes to be that not many agronomists secure anything like a complete set of the bulletins in which the results of research by other station or Department agronomists are published during any given year or period.

Hence, as a means of conveying the results of research to other agronomic workers, it would seem that the technical bulletins have some undesirable limitations.

On the other hand, there is something to be said from the standpoint of maintenance of the integrity and reputation of the experiment station against the promiscuous scattering of the results of its research work through many avenues of publication. Some station administrators have held that in order to be sure that a proper appreciation of the quality and quantity of output in research of the station shall be maintained in the minds of its constituency all of the publications of results of station work must appear in bulletin form, even though some of the technical articles may be printed also in scientific journals. However, many, if not a majority, of the individual stations are now providing for a "journal series" or "scientific contributions series" of articles which are to be published elsewhere yet are to be recognized as a definite part of the station's technical publications in addition to its own technical bulletins. If adequate means of listing and reviewing these journal articles are provided in the annual report or wherever else a complete summary of the station's publications for any given year or period may be presented, it would seem that this method would provide against a loss of institutional credit or of proper prestige from the failure to publish all the output of station research in its own bulletins.

Turning now to the question of the desirability of publishing results of agronomic research in scientific journals, it seems to the writer that this avenue of publication has many distinct advantages as well as some disadvantages.

In the first place, it tends to concentrate the material with which an agronomic worker ought to be familiar in a single, or at most, in a few, places rather than to scatter it through fifty or more series of publications. The degree of this concentration depends, of course, upon the number of journals which are open to agronomic papers and to which authors may send their contributions. But even at the worst, there is much less likelihood that an important contribution will be missed by students or abstractors if it is certain that it must appear in some one of a half-a-dozen or even a dozen scientific journals, than if it may appear in a bulletin which will not come to one's desk except upon special request. There is at present a rather deplorable tendency toward the multiplication in number and narrow specialization in field of scientific journals, especially in the general realm of biology and its applied sciences. This may have its advantage to the narrowly specialized scientist who desires to have his literature come to him very carefully classified in advance. But it has the difficulties which result from inadequate financing and small subscription lists as well as those of too narrow specialization, and there is apparently quite a probability that other scientific workers will follow the lead of the American Chemical Society in concentrating rather than in diversifying publication avenues in the future.

In the second place, publication in scientific journals secures more uniform standards of editorial treatment of the manuscripts of individual writers than is otherwise possible. There are many who regard this as not an advantage and that editorial standardization tends to eliminate desirable individuality in writing. Obviously this is true if the process is carried too far. But there are certainly many advantages, both to authors and to readers, in having literature citations made in accordance with definite accepted standards; tabular matter presented with column headings in forms which experience has shown to be clear and comprehensible; center headings in a uniform style which makes clear the relationships of different parts of the article; and other matters of editorial standardization.

Then, too, one needs only to review the current literature in any given field to discover that there are distinct advantages which accrue from extended acquaintance with the mechanics of the printing, etc., of a scientific journal. Paper quality, typography, the preparation of electroplates and etchings for illustrations, and a score of other details in the mechanical process of putting a manuscript into printed form become familiar through experience to the editorial staff of a scientific journal. Some of this experience is available to members of the staffs of our larger research institutions through their own editorial departments. But a lamentable number of station bulletins still indicate that these matters are determined more by the caprice of a small local printing establishment than by wider experience gained in connection with more frequent and more extensive publication service.

It will be apparent that the advantages to authors from publication in scientific or technical journals are to a large degree commensurate with the size of the journal, both in its circulation among other scientists and in the quantity and quality of editorial service that it can render. This is another argument for the desirability of a few strong journals, well supported and efficiently edited, rather than a multiplicity of weaker ones which cannot possibly give the same advantages to authors and readers.

On the other hand, it may be said that a good paper may be most effectively "buried" so far as reaching its proper audience is concerned if it is published in the wrong journal. Libraries are not all-inclusive. Abstractors, or reviewers, are not omniscient. A paper which is read at some local meeting and then printed in the proceedings of that meeting or society which are issued only to local members or in very limited editions with no general distribution is almost as effectively buried as if it remained in the author's desk. Some papers are published in most unexpected places, either because of personal preferences of authors or of some lack of familiarity with the generally accepted avenues of publication of material in this particular field, restrictions of publication privilege to members of societies, or other determining factors. Many such papers are bound to escape the notice of even the most careful reviewer of the literature of his field or problem. Some distressing instances of failure to recognize previous contributions to a given problem are traceable to the fault, or misfortune, of the first author in publishing his material in an out-of-the-way place rather than to any unusual or inexcusable lack of care by the second writer in reviewing the literature of his subject.

Probably enough has been said to show that the writer of this paper is inclined to answer the question which he is supposed to be discussing chiefly on the basis of how best the making of the results of one agronomy research worker available to other workers in the same field can be accomplished. He is not overlooking or minimizing the importance of making these same results available in usable form to farmers or teachers of farmers; but is setting that problem aside as not within the scope of the present discussion. He believes that the whole matter of publication, beginning with the preparation of the manuscript itself will be different depending upon the audience for which the material is intended.

Limiting the discussion then to the publication of the results of agronomic research for the use of other agronomists, the writer is of the opinion that the largest audience of most interested readers will be most effectively reached through publication in a scientific journal which has a wide circulation among other workers in the same field. There are numerous instances in which he recommends to members of his own station staff that their contribution be printed as a technical bulletin of the station. But these are generally when there is no suitable scientific journal in which the paper would reach a satisfactory audience or receive adequate distribution. Also, in certain fields, the publications of his particular stations have come to be generally looked to as the avenues for certain types of contributions. But here, as elsewhere in this discussion, it is the guiding principle that scientific research material ought to be published where it will most efficiently reach the largest number of interested readers.

Having once settled the question of the desirable place of initial publication, upon the basis of this principle, to be in a scientific journal, it would seem to be possible to guard the institution's rights to credit for its origin and prestige for total output by suitable record and review of "journal series" articles in some annual summary of station publications, or by simultaneous or subsequent publication of the material in bulletin form if the latter would give adequate additional publicity of the material or recognition of the station's contribution to agricultural knowledge to justify this additional expense.

2. THE TECHNICAL BULLETIN AS A WRITER SEES IT[1]

CARLETON R. BALL[2]

The very title of this paper itself raises some interesting questions. Writers are diverse. They differ in education, training, experience, ability, and sympathy. The word sympathy is used here in its exact meaning of feeling with others. If writers are diverse, their viewpoints concerning technical bulletins are likely to be equally diverse. This topic may be developed so as to present a composite picture of the ideas of writers as a genus. On the other hand, it may be developed to show the diverse viewpoints of different writers as individuals. It is hoped that it may do both.

PERSONAL FACTORS

There are some considerations personal to the writer that must not be forgotten. These are (a) his impatience for publication, (b) his sense of ownership or kinship in his product, and (c) his own particular limitations. Some or all of these influences are sure to be factors in every publication.

IMPATIENCE

The writer of a technical bulletin presumably has spent months or even years attending to the numerous complex and oftentimes tedious details of the investigation upon which the publication is based. Many data have been assembled and interpreted. Certain important or possibly fundamental facts stand out. The investigator wishes to present these facts to the public as quickly as possible. He is impatient to do this for several reasons. The work has been done and he wishes to see the results in print. His mind is now centered on the next phase of the study, or on a new line which he is developing, and he wishes to be free from consideration of the old. In the third place, writing often is a laborious and uninteresting process to an investigator and he wishes to have it over as quickly as possible.

KINSHIP

A manuscript is a part of the very life of the writer. It is more than the product of his hand. It is the product of his mind, heart, and soul, because the best of his mind, heart, and soul have gone into the studies on which it is based. It is the intimate expression of his labor and his genius, a veritable child of his creative faculties, as dear to him as a child of flesh and blood. Those who deal with it later should remember these things, if they are to be helpful to the author.

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[1] Paper read as a part of the symposium on "Publication of Results of Agronomic Research" at the meeting of the Society held in Washington, D. C., on November 18, 1926.

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LIMITATIONS

This sense of ownership, almost of kinship, tends to blind him to the sins of omission or commission which it may contain. The poet's prayer, "Oh, wad some power the Giftie gie us, to see oursel's as ithers see us," was never more needed by any one than by the writer of bulletins. The man who can not write correct English does not see his ungrammatical constructions. The man who has a limited vocabulary does not realize the lack of clearness which results from his failure to use words carrying exactly the meaning or shade of meaning desired. The man whose style is verbose and redundant does not recognize the verbosity and redundancy of his writing. The man who is accustomed to long and complex sentences does not perceive the value of short, concise statements. Because he is unable to see the errors and faults of his work, he may be indifferent to suggestions of needed change, and resentful of changes made.

What is the remedy for the effect of these personal factors? Obviously, true perspective is the only remedy. The writer needs to stand off and study his product from new and different mental angles or viewpoints. First, he should put it away and let it get "cold." This may require ten days, or two weeks, or a month, depending on the person and on how completely he can forget it. At the end of this necessary period the writer can read his paper with something of the impersonal viewpoint from which others see it. Then only can he appreciably better it.

SCOPE AND CONTENT

It may be supposed that all writers would agree as to the purpose of a technical bulletin. This is by no means certain. It is probable that some look upon the bulletin as a repository of information, a sort of receptacle into which all available information is poured for safe keeping. This makes for an encyclopedic type of publication, often of much reference value but likely to be large, expensive, and not adapted to general use. It is probable that a larger number regard a publication as a vehicle for the conveyance of their ideas to others. Assuredly the latter is the correct viewpoint, though if the bulletin be a conveyance it must first of all be a receptacle.

Agreeing that the purpose of a technical bulletin is to contain and convey technical data, the question falls on the scope of these data. In general, the writer wishes to present five series of facts. These are: (1) A review of the literature of the subject, (2) the materials, methods, and conditions of the experiments, (3) the assembled results of the investigation, (4) a summary of the important data, and (5) a list of literature cited, or a bibliography.

In any given bulletin there may be a departure from this scope. If the subject is new, there may be no literature to review. If the subject is narrow, no review of literature may be necessary. If the paper is one of a series, each presenting results obtained with a single variable in materials, methods, or conditions, the discussion of the nonvarying factors may not be repeated each time. If the subject is comparatively new, there may not be a bibliography. For most pieces of investigation, however, the scope of the presented results will cover these five points.

REVIEWS OF LITERATURE

In reviewing the literature of his subject, the investigator should present the work and conclusions of other investigators as completely and yet as concisely as possible. Each review should be brief, clear, and accurate. There is the widest difference in the abilities of different writers to summarize the essentials of published data. Not all reviews meet these specifications. The temptation always is present to sacrifice brevity in a desire to make them complete. It is easier to write many words than few. It also seems fairer to an author cited to discuss his qualifying statements as well as his primary conclusions. In other cases, the reviewer fails to distinguish between those papers which are important and those which are not. He treats all alike, and either generously or briefly, as the case may be.

Perhaps the greatest weakness of reviews of literature is the incompleteness. This may be due to several causes. The investigator may be self-centered and indifferent to the work of others. He may be pressed for time or lack adequate library facilities. Often he is not fluent in other languages than his own and, therefore, is inclined to neglect papers of foreign investigators. The reviews of literature are important and necessary. They are worthy of the best attention of the writer, not only for their own sake but because their quality is an evidence of the breadth of his perspective on the subject.

MATERIALS, METHODS, AND CONDITIONS OF THE STUDY

This chapter of a technical bulletin is the basis of more controverted questions than almost any other. It explains the material used, the methods employed in doing the work, and the conditions under which it was done. Without a clear understanding of these facts, it usually is impossible for the reader to obtain a basis on which to judge the dependability of the results presented.

It is of primary importance that the material used in an experiment be clearly and accurately described. This is imperative if living material is used. Evidence of uniformity of the material is especially important if portions are to be subjected to different treatments and the results are to be compared, as is usually the case in most experiments.

The methods of performing the experiments and environmental conditions require clear presentation. The spacing of individuals or of rows, the number and the distribution of replications, and the physical environment (temperature, moisture, soil, etc.), all must be given briefly but clearly, if they could have influenced the results.

The sequence of the various experiments which make up the investigation in hand also is of primary importance to the reader. Some authors refer to them as Experiment 1, Experiment 2, Experiment 3, etc. This may be a satisfactory method if the total number is small. If the number is large, however, it is a severe tax on the memory to recall just which experiment was No. 3, or No. 6, or No. 10, as the case may be. It is preferable to use some key word or key phrase in designating each experiment, if possible. These key differences may be in the variety or strain of the organism, in the age or state of development of the organism, in the kind or quantity of chemical substance used, in the physical environment (light, temperature, moisture, etc.), or in something else connected with the technic. Usually, the necessary key word or the brief key phrase is easily selected. No matter what the designation employed, it is of the utmost importance that the sequence of operations be clearly shown.

It may seem that the matter of attention to materials, conditions, and methods is being over emphasized. Let us consider the psychology of the investigator. He is concerned primarily with results and conclusions. They are the things of the immediate present which he is trying to set forth in a logical and convincing manner. Materials and methods, at this stage of the investigation, are things of the past. They are of little immediate interest to him. Furthermore, he recognizes the importance of the results, while the materials and methods now seem relatively unimportant. They were all in his mind while he was doing the work, long before the results became apparent or the conclusions possible. He forgets, however, that they were not in the minds of others, and will never be unless he conveys them clearly. Many a good paper has been spoiled because these facts were so imperfectly presented that the reader could not determine from the text how the experiments had been conducted and, therefore, whether the results were accurate and the conclusions justified.

There is a pioneer publication presenting the results of early field investigation which is a striking example of this fact. It presents certain textual and tabulated data and arrives at certain conclusions. It does not state the location of the experiments. It does not give the duration either in total time or in the actual years covered, and it omits all mention of the methods of conducting the investigation. As a piece of scientific writing, it is practically valueless.

New terminology.—This is a phase of the discussion of materials and methods which entails heavy obligations. Often these obligations are not recognized and met. In the rapid development of new branches or phases of science, it is necessary that new terms be created to express the new ideas involved. Each worker may find it necessary to devise new terms. It is easy to launch a term which sounds well but means something quite different from what the average reader would understand it to mean. It is almost impossible to correct this impression, once established. A case in point is the term "biologic form," which has been used so extensively in the literature of rusts in the last ten years. Biology is the science which treats of living matter—of life. The word "bios" means just that. A biologic form, therefore, is a living form. Obviously every organism in the animal and plant kingdoms is a biologic form under any reasonable definition of this term. Yet the phytopathologists wished to limit the meaning of this broad and comprehensive word "biologic" and make it apply to a fungus entity of the fourth taxonomic rank. Happily, the matter is now adjusted, through the work of a committee representing three great National societies, including our own, and the phrase "physiologic form" has been substituted for the objectionable and confusing one.

Definition of terms.—Another obligation on the writer of bulletins is to define any new or unusual terms used in his paper. This obligation also often is neglected. The worker is likely to devise and use the new terms long before he publishes his results. By the time his manuscript is prepared, the new term has become an old one to him. He may forget that others do not know or understand it and that a clear definition is required of him. There have been some striking and unfortunate examples of this practice.

RESULTS OF THE INVESTIGATION

Results may be presented in the form of text, tables, and illustrations. In any case, there is the utmost obligation for clearness and accuracy. The textual discussion should describe the conditions of each particular experiment so far as these are not covered in the chapter on materials, methods, and conditions. It should point out the principal facts which the experiment revealed, with appropriate reference to tables, graphs, or other illustrations. It should summarize briefly the conclusions which may be drawn. This should be done for each successive specific experiment of which the results are presented. Care should be taken to arrange these experiments in a logical order or sequence. In this portion of the manuscript the use of proper headings and subheadings is of the highest value to the reader.

The preparation of tables probably is the most difficult part and the least easy to change after once completed. It really is an art in itself and should be taught widely. The table is composed of three parts, the title or legend, the column headings, and the data.

The title should be full and complete even to the point of repetition of textual statements. This enables the reader who is attempting to compare the data in one table with those in another to determine quickly the contents of each and to be sure that he is comparing the right sets of facts. It also enables the reader certainly and quickly to connect any given table with the text discussing it.

Many table legends appear to be constructed on the theory that a bulletin or paper always is read from the beginning on to the very end at one sitting. This rarely is the case, at least after the first reading. A paper really is a reference work and the user should be able to study and interpret a table without much, if any, reference to the text.

The same sequence of phrases should be used in the titles of all related tables, in order that the differences of content between one table and another may be recognized quickly. Frequently there will be a series of tables differing one from another by a single variable. For instance:

"Table 1.—The ash content of irrigated wheat."
"Table 2.—The protein content of irrigated wheat."

Suppose, however, that this last had been written, "The effect of quantity and time of irrigation on the protein content of wheat?"

No reader could be sure that the two tables covered different but comparable data from exactly the same experiment. Of course, both titles might preferably be in the fuller form last given.

No portion of a table is more neglected than the column headings. It is of the utmost importance that they show clearly, fully, and simply what data are placed in the subtending columns. Examples of carelessness and inaccuracy come readily to mind. Such practices place on each of perhaps hundreds of readers a burden of labor which should have been assumed by just one person—the writer. The obligation is for completeness, logical arrangement, and accuracy.

Even though a table title is full and complete, column heads should not be omitted. Rather than this, the title should be abbreviated. Recently a research bulletin presented ten correlation tables in which only the subject was named in its single column heads, while the reader was obliged to seek the missing headings for ten or a dozen relative columns in the title of the table. This makes for loss of time and vexation of spirit.

In arranging column headings, the universal rule is to proceed downward from the more inclusive to the less inclusive. Column headings really are vertical keys, similar to the horizontal keys used for delimiting species and varieties of plants and animals. The broader divisions are indicated first, and then the successively narrower subdivisions. The last subdivision naturally indicates the content of the individual column. In some cases, it is noted that writers put the lesser before the greater, or repeat the greater for each column.

It would be thought that little need be said about the data in the columns themselves. Unfortunately, long experience has proved that this is not true. There is a most tremendous obligation that the data be accurate. The intention of the writer always is good, but good intentions often are but paving stones for Hades and other hot places. Sometimes the individual data are incorrect, sometimes columns are incorrectly added, and at other times the calculated averages are not accurate. As a result, the final data lead to erroneous conclusions.

Accuracy is more a matter of habit than of ability. Writers must strive to get the habit of accuracy. There is a certain publication of a research institution, from the pen of a man known internationally, the tabular matter of which is full of mathematical errors. The subject was one of fundamental nature and of wide-spread interest in science and the bulletin has been widely used. It would be better had it never been written or published. Missing or incomplete data constitute another problem for the reader. Blanks or gaps in tabulated data should be explained clearly. Oftentimes blanks or dashes occur in tables, without explanation. The reader is left to guess whether the corresponding portion of the experiment was not conducted, or whether the results were lost, or were negative.

THE SUMMARY

A concise summary of the results obtained and the conclusions drawn is an obligation on the writer. The research must be studied in detail by the specialist. Only the summary of results and conclusions will be read by others than the specialist. Even the specialist is entitled to get a bird's-eye view of the results, or to refresh his memory, without wading through many pages of detailed data.

The chief obligation is to see that the summary really summarizes. A recent paper carried a chapter headed, "Summary and Conclusions." It actually contained not a single word of summary and the so-called "conclusions" were an entirely new discussion of qualifying data. Another obligation is to present the summarized data in the same sequence as the original detailed data and to insure that no important point is omitted.

THE LITERATURE CITED, OR BIBLIOGRAPHY

There are three important characteristics of a list of literature cited, or a bibliography, namely, (1) accuracy, (2) completeness of citation, and (3) arrangement. In the case of a bibliography there is an obligation also for thoroughness.

There is the same obligation for accuracy in a bibliography as in the other parts of a bulletin. This applies to the spelling of names, the transcribing of the title, the correctness of the citations of volume, inclusive pages and illustrations, and the date. Experience teaches that errors are to be found in bibliographies, as elsewhere. In larger institutions the references usually are verified by the library staff, but in most institutions, including some of the larger, this is not the practice. The responsibility then rests directly on the author.

Unquestionably, there should be conference and consequent agreement on the form of citations of literature. At present, there is the utmost and exasperating variation. Wherever possible, the title of a paper should be given in the original language. When the title of a paper is translated and the original title is not given, the translated title should be followed in parentheses by the phrase "Translated from the German," or whatever the original language may have been. Where the original title is in Chinese, Japanese, Russian, Polish, Greek, Hebrew, Arabic, or some language not using the English alphabet, translation usually is desirable, and the omission of the original title may be necessary. Some authors, however, make a practice of translating titles from French, German, Italian, Swedish, etc., and omitting the original title.

For clearness, convenience, and accuracy, the inclusive pages and inclusive figure and plate numbers should be given instead of merely the total number of each. Some citations omit all reference to illustrations, others merely insert the abbreviation "Illus." In cases where the figures comprising several plates are numbered consecutively throughout the series of plates, some writers cite both the inclusive plate numbers and the inclusive figure numbers, thus creating a very erroneous impression of the total number of illustrations.

Writing, typing, printing, and reading citations of literature is a tedious and expensive process at best. The most simple form which tells the story clearly is the least expensive of time, effort, and money. A simple and uniform practice has been adopted by many of the larger scientific journals. In the simplified form the words or abbreviations for volume and pages are omitted. The volume number is followed by a colon which, in turn, is followed by the inclusive pages. After this comes the designation of figures and plates, both inclusive, and then the date. This simplified practice has been adopted by such abstracting journals as *Biological Abstracts* and *Botanical Abstracts*, and by such biological journals as *Botanical Gazette*, *Journal of the American Society of Agronomy*, *Journal of Agricultural Research*, *Plant Physiology*, and many others. This simple and easy system is in striking contrast to the cumbersome citation used by some other journals in this country and abroad.

IN CONCLUSION

In conclusion, you will have noted ere now that this topic has been presented from the viewpoint of what the writer owes to his colleagues who must read. Scientific results are not largess to the inferior or alms to the needy. They are facts determined for the physical, mental, or moral welfare of mankind. In making their offering, the votaries of Science must be willing to give their best. Less than the best is unworthy of the writer and unfair to the reader.

3. CHARACTERISTICS OF A GOOD JOURNAL ARTICLE[1]

M. C. MERRILL[2]

INTRODUCTION

To formulate the characteristics of a good journal article is difficult. There is no absolute standard or universally accepted formula by which one can be guided. Personal opinion enters so largely into the consideration that positive assertions by anyone may very properly be questioned. So much depends upon the subject, the author, the reader, the journal, the period of publication, and the available space and funds, all of which are subject to wide variation, that what would be rightly regarded as desirable characteristics of a journal article under certain conditions might not be so regarded under other conditions. This is particularly true if the article is judged by different persons.

The personal element of the problem may therefore be given first consideration. Who is to judge a finished journal paper and say whether it is good, poor, or indifferent? The first, and unquestionably the severest, critic should be the writer himself. Human nature being as it is, however, and the limitations of time playing such an important rôle, it can not be expected that the busy writer will always subject his work to cold-blooded critical scrutiny. The second critic is the journal editor or editorial committee who aim to pass impartially upon the manuscript from the triple standpoint of the author and his problems, the journal and its financial difficulties and space limitations, and the subscriber, who has a right to expect that reasonably rigid standards will be maintained in the articles published in the journal for which he is paying. The third critic is the reader. He is commonly the most severe of all. If the writer will bear in mind that every reader of his paper is a potential critic and if he will accordingly take pains to avoid loopholes for attack, his paper will undoubtedly be much stronger.

The process of preparing a journal article is similar in some respects to the building of a house, the author being comparable to the builder who is also to be the owner. There is this important difference, however, between the two finished products—the house and the printed paper. The one may be torn down in the course of time or crumple away and vanish from the earth; the other remains perennially. The printed pages are placed in orderly repositories where they are carefully safeguarded for the generations to come. Hence, how extremely important for the builder of a manuscript to exercise the utmost care in its preparation! Although his mistakes may be buried in a library there is no telling when they may be exhumed for further examination.

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[1] Paper read as a part of the symposium on "Publication of Results of Agronomic Research" at the meeting of the Society held in Washington, D. C., November 18, 1926.

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We have heard a good deal in recent years about the desirability of cooperation between workers in scientific research. The need for a certain type of cooperation is evident in many papers which have been written and published without having had the benefit of careful scrutiny and helpful criticism by the author's coworkers. It is difficult under such conditions for a paper to become possessed of all the characteristics of a good journal article.

Can a writer see all the faults in his own paper? In his eyes are not even the faults in this offspring of his likely to become metamorphosed into virtues? Here is where the editor or other critical readers of a manuscript are given opportunity to render valiant service, which, however, is often unappreciated. Although it is not to be supposed that all of the suggestions or alterations made by the editor and other critics invariably indicate the best course or result in improvement, yet, by and large, they are helpful and make for the betterment of the paper. And it should be remembered that these impartial critics have in mind not only the problems of the author but the service the paper is going to render to the readers. It is to protect the paper from faults which will make it subject to justifiable criticism after it is published that the pre-publication comments and criticisms are made, and they should be welcomed. The highway of scientific publications is strewn with the wrecks of careless operators caused either by speeding to press or indifferently bumping into some subject when the mechanism was not properly reinforced to withstand the resulting jar.

BASIS OF CHARACTERIZATION

Now what shall be our basis for indicating the characteristics of a good article in a scientific journal? What are the factors to be taken into account? Although there are many ways of looking at the problem, the following subjects appear to be fundamental: (1) Character; (2) purpose; (3) scope; (4) technic of presentation, including content and arrangement; and (5) form and finish.

CHARACTER

A distinguishing feature in the character of a scientific journal article is that it is scientific. The article is based on facts. It is informative. It is not designed to persuade to action, although it may be argumentative. But how argumentative? You can all recall supposed-to-be scientific papers that contain a gram of experimental data and a kilogram of theoretical argumentation. The question might appropriately be asked, why argue about demonstrated facts instead of letting them speak for themselves? Technical writing should recognize clean-cut distinctions between fact and theory, knowledge and belief, accomplishment and propaganda.

The technical article must have stability and dependability. Its foundation must be well laid and reach down to solid substantial data derived from careful experimentation or study. The reader must have confidence in it. There must be no trickiness and no subterfuges. The structure must be substantial and enduring, not flimsy and temporary—it must be solid stone, not stucco.

An element in the character of technical journal papers that is sometimes overlooked is that they are technical, and are written for those who can understand them. They are therefore written in the language of the profession, and it should not be necessary to define, explain, or discuss the terms and principles that constitute the college course in the subject. The author of one of the *Journal of Agricultural Research* papers could be only partly convinced that his paper was made much stronger by the omission of a detailed discussion of elementary principles of chemistry and physics as applied to soils which are studied to-day by even high school students. In another case it took a two-hour argument to persuade the writer of a technical bulletin to consent to the elimination of about 30 pages of introductory elementary material with which any freshman college student of the subject is acquainted.

PURPOSE

What is the purpose of technical writing? Is it to enable workers to establish reputations for achievements in science, or is it to make contributions to scientific knowledge? In a good journal article the subject and the results are of paramount importance and the personality of the author is kept subordinate. His viewpoint is objective, not subjective. The data are therefore objectively considered for what they are worth. That highest type of honesty—scientific honesty with one's self—should be a guiding influence in presenting the results and conclusions to the world. Prejudice and personal bias should play no part whatsoever. If the data run counter to the writer's pet theories, they should nevertheless be courageously given even though the writer thereby fails to attain scientific eminence. If fame comes to the scientific writer as a by-product of his contribution, well and good. But the underlying purpose for which he writes, however, should be to increase the world's knowledge, not his own prestige.

It is a strange thing that many scientific workers are aglow with enthusiasm in the prosecution of that part of their research pertaining to the obtaining of data which blaze the way to new truths, but when the discovery is made and the scientific curiosity satisfied the authors are very loath to stop, sit down, take stock, and carry on the laborious process of assembling, verifying, tabulating, comparing, and checking the data, and especially of interpreting, explaining, and discussing them and pointing out their significant relationships. Under such circumstances writers are apt to forget or not be fully conscious of the purpose of their writing and of the fact that the ultimate value of research is determined by either its use or its availability to others. Publication of the results in creditable form should therefore be a paramount consideration.

SCOPE

The scope of a journal paper needs careful attention at the outset. How broad and inclusive, how narrow and exclusive, in other words just how comprehensive should it be? Should it be short and confined to a single aspect of the subject, or should it be long and monographic and give relatively complete information about a certain subject? Apparently here is a field upon which no hard and fast lines can be drawn. So much depends upon the subject, upon the writer's relation to it, upon the extent of the investigation and the nature of the results.

Unnecessary length and extreme brevity should both be avoided. We are all familiar with journal papers which are so long and disjointed, and the parts so distantly related, that we wonder why the material was not presented in two or three concise articles. On the other hand, there are impatient workers in science who burden the literature with fragmentary bits of information. This frequent rush into print with these fragments gives rise to the suspicion that the author cares more about seeing his name in print than about adding to the difficulties of his coworkers who may be earnestly trying to follow his work. Such practice unnecessarily clogs the lists of "literature cited." One solution would be for journals to refuse to accept such fragments for publication until they had been joined into an important constructive contribution.

TECHNIC OF PRESENTATION

The technic of presentation includes several important phases that must be carefully considered. When a reader picks up an article on a scientific subject certain questions naturally come to his mind, and if he is much interested he will not be entirely satisfied unless all the questions are answered. These questions may be indicated telegraphically by the single-word forms, who, where, when, why, how, what, and whither.

Who is the author, where and when was the work done, why was it undertaken or what is its purpose; how was it done, i. e., what were the methods, apparatus, and technic, and what are the results; whither does it lead or do the results show progress in a given direction, and what may we conclude from them?

These questions will probably be most satisfactorily answered if the arrangement of the material is orderly and logical. If science is organized knowledge, might we not expect that a scientific contribution will be well organized? The natural order of treatment for the usual journal article would seem to be: (1) Title of article, name and title of author, and the place where the work was done; (2) introduction; (3) review of literature; (4) methods of experimentation; (5) data; (6) interpretation of data; (7) conclusions; (8) summary; (9) literature cited.

Title.—The choice of an appropriate title for a journal article is sometimes very difficult The title should be brief, concise, and indicative of the content of the article. It must not be too brief, however, or it will be vague. "Growth" as one title and "The Conditioned Reaction" as another do not give one much idea of the content of those publications.

The following titles found in journals are given as examples of long unwieldy ones:

"Studies of the formation and translocation of carbohydrates in plants. III. The carbohydrates of the leaf and leaf stalks of the potato. The mechanism of the degradation of starch in the leaf."

"The controlling influence of carbon dioxide. IV. On the production of secondary dormancy in seeds of *Brassica alba* following treatment with carbon dioxide, and the relation of this phenomenon to the question of stimuli in growth processes."

"The orientation of molecules in the surfaces of liquids, the energy relations at surfaces, solubility, adsorption, emulsification, molecular association, and the effect of acids and bases on interfacial tension. (Surface energy VI.)"

When the arduous work of citing and indexing long titles is considered, would not the following shortened forms be much better?

"Some relations of carbohydrates in potato plants."

"The effects of carbon dioxide on the seeds of white mustard."

"The orientation of molecules in the surfaces of liquids, and related phenomena."

In a technical journal article there should be no serious objection to the use of binomial Latin names for plants and animals when exactness is necessary. But in many cases it surely seems as if the use of the simpler common name in English would improve the title.

A common title noted in the literature begins: "A contribution to our knowledge of." Would it be much more obvious to begin a title with:

"An illustrated journal article giving information about?"

Again, there are those papers in a series usually denoted "Studies" or "Investigations" of some many-angled problem. There is the main heading for all the articles in the series followed by the specific title preceded by the Roman numeral I, II, III, IV, etc. If we could forget about the clumsiness of titles of this type and the difficulties of citation, we would not have serious objection to them. But when, as often happens, this promising series is launched with No. I, and coworkers are expecting the succeeding articles which for some reason never come, there is good ground for very serious objection to this method of giving titles. Why not let each article stand on its own feet and speak for itself?

Following the title the writer's name should be given in such form that he can be identified by his coworkers. His position, rank, or title are also of interest if not of importance and should be correctly given. Finally, the location or institution where the work was done should be included. Hence, after the title is noted the questions who and where are answered.

Introduction.—Some authors plunge so suddenly into their subject that the reader must begin to struggle at once in the strange surroundings to get himself properly oriented before he can proceed. It is ordinarily considered better to introduce the reader more gently and formally to the subject. He is thus informed in sufficient detail of the purpose of the experiment or research, and exactly when and where it was performed. The specific relation of the present work to previous research, if any, along the same line should also be given in order that a proper orientation of the field may be had at the outset.

Review of literature.—Here there should be careful discrimination and rigid selection. As the number of trained workers has increased and research facilities have multiplied, the output of scientific literature has mounted to unprecedented volumes. The young worker who is preparing a thesis to pass muster for the Ph.D. requirements usually responds to the ambitious urge to review all that was ever published along his line of study. By means of extensive reviews some papers in the course of time are reviewed time and again, and naturally the experienced research worker considers them largely a waste of time and space. In fact some have gone so far as to suggest that inasmuch as the workers especially interested in a particular subject are already familiar with the literature of the field or have avenues through which they can obtain the information, technical papers should omit the review of literature. Instead of going to either one extreme or the other would it not be very much better to continue to give the review of literature in a standard paper, but limit it to a very brief statement regarding important contributions having a direct bearing on the work in question? In that way the research reported is oriented into its proper historical setting and the question whither it leads receives answer.

Methods of experimentation.—The question "how" should be answered fully and clearly. Other workers in the field may wish to duplicate the work. To do so they should be able to understand the methods, apparatus, and conditions under which the work was done. If the technic is new or difficult to understand, drawings or pictures are very desirable. At this point it is well to note that apparatus or technic which may appear very simple to the writer may be very difficult for others to understand. It should be noted, however, that while the reader's information should not be overestimated, neither should his intelligence be underestimated. Hence when the method is once described it is not necessary to repeat in later parts of the paper what has already been given.

Data.—In the prosecution of research it must needs be that data are obtained. They are the materials of which scientific discoveries are made. Notebook after notebook becomes filled with them. But how are they to be handled in preparing a manuscript for publication? That is one of the big problems which the writer faces. Many processes are used for the extraction of the data from the materials at hand, but whatever the process each figure is obtained with some effort and after much planning and deliberation. Naturally all the data are therefore prized, for they are in large part the offspring of pains, ingenuity, and forethought. Hence the writer often finds it difficult to discard any of them, and finally considers that the only just and impartial plan is to include them all. The result is table after table of detailed figures of little significance. From the viewpoint of the reader he has not properly evaluated and segregated his data. Many a lifeless paper has been vitalized by a proper grouping, classification, and summation of data into significant values readily seen and appreciated.

Most data are presented either in tabular or graphic form. In this paper only the tabular form will be discussed. Properly prepared, a table has unified organization and logical order and is not a conglomeration of unrelated figures. The primary purpose of a table is to group and arrange the data so that significant relationships may be readily comprehended. Hence if a table is not clear or easily understood it largely fails of its mission.

Interpretation of data.—Now that the data are all assembled, assorted, and assimilated, what do they mean? What is their significance? Shall the reader be left to guess? This happens in many papers. The writer apparently feels that his duty is fully done—that he has given the reader the facts, let him analyze and interpret them as he wishes. The natural result is that the data will go down in history uninterpreted, unwept, unhonored, and unsung.

Another type of misdemeanor for which there should be jail penalty is the listless repetition in the text of the data that can be seen much more plainly in the tables, without any attempt to indicate significant relationships or to interpret them in any way whatsoever.

In the interpretation of data it is exceedingly important that the author base his analysis upon the figures as they are and be guided accordingly. Some papers show evidence of bias in favor of certain conclusions which are not substantiated by the data. A manuscript submitted to the *Journal of Agricultural Research* had to be rejected because the author drew conclusions in support of a fine theory from data which in themselves were hopelessly conflicting and inconclusive.

Conclusions and summary.—Too often there seems to be confusion regarding the conclusions and the summary. These have entirely different functions. The conclusions come naturally after a logical discussion in which various phases of the subject are analyzed, weighed, and balanced against results presented by others. The conclusions of a paper constitute the essence of the author's interpretation of his results. The summary is just what its name implies. In very abbreviated form it summarizes the important points in the entire paper.

For the average reader the sections containing the conclusions and the summary are the most important parts of a scientific paper. Here he will turn first to get a bird's-eye view of the paper and to ascertain what it is all about. If he is especially interested he will turn back and read all or parts of it, but if he is interested only in a general way he will be entirely satisfied with the information in the summary if it is well prepared.

Literature cited.—The references to other papers are of two general classes: (1) Literature cited, and (2) bibliography. Often they are not clearly distinguished. "Literature cited" properly includes only those references cited in the text. "Bibliography" may include any references bearing upon the subject of the publication, whether they are cited or not.

Ordinarily a journal paper should confine its references to those which are actually cited in the text. If few in number, for example, fewer than seven, they might well be placed in footnotes; if more than seven, in a list at the end entitled "literature cited." The appropriate place for bibliographies is in monographs, books, and special publications.

That all such references should be accurately given goes without saying. The system of citation should also be simple, convenient, and serviceable.

FORM AND FINISH

Science is exact and its language should be precise. Any one, therefore, who writes a scientific article should be painstaking in his choice of words, and these should precisely express his meaning. Not infrequently a sentence is subject to two or more interpretations. The writer knows definitely which he had in mind but not so the reader.

Closely related to precision in the use of words is clearness. This quality in writing is intimately associated with clear thinking. If clearness and logic characterize an author's thinking, these virtues are likely to be reflected in his writing. Many scientific papers are exceedingly well written. Others contain vague or needless words or words used incorrectly. Common faults are the use of abstract words instead of concrete and the hopeless mixture of the two in the same sentence. For example, can one analyze the sugar *content?* What are *rooty* characteristics? Can the starch content of potato *varieties* be determined? Does the *presence* of water puddle the soil? When did a *condition* of saturation lower the temperature? One critic calls such writing "jargon," as also the indiscriminate use of such phrases as, "on the basis of," "in the prosecution of," "the occurrence of," "the proposition," "from the standpoint of," "according as to whether or not," "in the case where," "in connection with," "the situation in regard to."

A consideration much neglected in scientific writings is brevity. Brevity is not altogether determined by number of pages. Some manuscripts of 10 pages are too long, others of 50 pages are too short. Lack of brevity is an indication of lack of definiteness in the writer's mind or of appreciation of the reader's intelligence, or both. Coupled with this lack there is commonly a failure to discriminate between the essential and the unessential. As in the tabular matter, so in the text the author puts in written form many ideas which were incubated during the experiment but which have no real function in the presentation of his results. Probably the worst sin against brevity, however, is needless and tiresome repetition. Instead of lending emphasis it arouses exasperation.

The purpose of scientific writing being serious, the style should be conservative and appropriate, and free from indications of striving for flashy uniqueness so characteristic of modern composition. Simplicity not only of expression but of arrangement should be sought. Roman numerals so long in use for numbering tables, plates, text figures, journal numbers, and volume numbers should give way to Arabic.

A good article will have been rewritten and revised several times before it is considered to be in final form. No matter how well a man writes, his first draft of a paper can be improved. Only the literary genius can run off a thoroughly satisfactory article on the first writing, and he is seldom found in research laboratories.

But how the enthusiasm rises and the desire for a perfect product begins to burn when the author sees his manuscript in proof! Then it is that he perceives the numerous opportunities for improvement. There seems to be a common affliction among authors which renders them unable to see places needing improvement until the manuscript gets into print. If an author would at the outset give thought to the characteristics of a good article, take pains in its preparation, and revise it until he is thoroughly satisfied with it and it can withstand the onslaughts of critics, there will then be no need for doing more to the proof than correcting mistakes in printing. The whole process will require of the writer much effort, but it will be effort well expended.

4. METHODS OF GRAPHIC REPRESENTATION OF EXPERIMENTAL DATA[1]

J. D. LUCKETT[2]

The use of graphs as an aid in the interpretation of scientific data presents certain problems to the author and to the editor if the readers of scientific journals are to be served to the best advantage. It is the intent of this paper to set forth briefly a few suggestions regarding the preparation and use of graphs and charts in presenting agronomic data to agronomists without attempting to discuss the application of these devices to the popular interpretation of experimental results, valuable as they are for this purpose. Also, it should be stated at the outset that the writer is not qualified and will not attempt to discuss the mathematical aspects of the graphic analysis of experimental data, although appreciating fully the fact that at least an elementary knowledge of the mathematics involved is essential to the intelligent use of graphic methods.

Possibly, however, the purely editorial point of view toward the construction and use of graphs may have some elements of interest to those who contemplate the preparation of scientific papers. It is certain that much that will be presented here will be decidedly elementary in character, but perhaps the chief criticism to be brought against the graphic presentation of data in the JOURNAL of the American Society of Agronomy is a certain weakness that sometimes appears in the mechanical make-up of the charts and graphs submitted to the JOURNAL for publication.

A question that often presents itself to one who is about to prepare a scientific paper is how far to go in the use of graphs or other illustrations, and it is sometimes truly perplexing to determine just where to draw the line. Dr. Raymond Pearl[3] in his admirable work on *Medical Biometry and Statistics* says, "Even the most seductively constructed and arranged table of statistics will not convey the story which inheres in the figures with anything like the neatness and dispatch attainable by graphic presentation."

Dr. E. W. Allen in a discussion of "The Publication of Research" has this to say about the use of illustrations and graphs, "A good illustration is often the quickest way to convey an idea. Frequently, it will do the work of a whole page of description. The same is true of the presentation of results in graphic form, provided such graphs are not so complicated as to require an undue amount of study. The object of illustrations is to illuminate the text but not to embellish it—to make it more intelligible or to give a more definite impression." The writer can conceive of no better test of an illustration, whether picture or graph, than to ask if it makes the article more intelligible and leaves a more definite impression of the findings in the experiment under discussion.

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[1] Paper read as a part of the symposium on "Publication of the Results of Agronomic Research" at the meeting of the Society held in Washington, D. C., November 18, 1926.

[2] Editor, New York State Agricultural Experiment Station, Geneva, N. Y.

[3] PEARL, RAYMOND. Medical Biometry and Statistics. Philadelphia: W. B. Saunders Co. 379 pp. 1923.

Having decided to make use of graphs for illustrating his results, the author will find that the form which the graphs should take will be determined very largely by the nature of the data which he has to present. The characteristics of different forms of graphs and the uses to which they are best suited will be discussed briefly in the following paragraphs.

To quote again from Dr. Pearl, "All statistical diagrams are representations of points, lines, surfaces or solids, the positions of which in space are quantitatively defined by a system of co-ordinates." These co-ordinates may assume different forms, but the commonest sort are rectangular in outline.

In addition to rectangular co-ordinates there may be angular co-ordinates, such as occur in the so-called "pie" diagrams, polar co-ordinates, and geographical co-ordinates used in statistical maps where latitude and longitude are the axes of reference. Probably for most purposes in presenting agronomic data, however, rectangular co-ordinates will be found most suitable.

Certain types of diagrams are much better fitted than others to the telling of the story, and Dr. Pearl has formulated a classification in which the principal types of diagrams are divided into four groups according to the use to which they are to be put. His classification is as follows: (1) To represent frequencies of things, (2) to represent trends of things or events, (3) to show geographical distribution of things or events, and (4) to facilitate or replace computation.

Agronomists will probably be concerned chiefly with the construction of graphs which represent the frequencies and quantities of things, and the form of the diagram will depend on whether the things to be compared vary continuously or discontinuously. Two types of diagrams may be suggested for representing discontinuous variations, namely, the "pie" diagram and the bar diagram. Both of these are used effectively in the popular presentation of agronomic data, but it is doubtful whether the pie diagram has a place in a technical paper such as would be suitable for publication in the

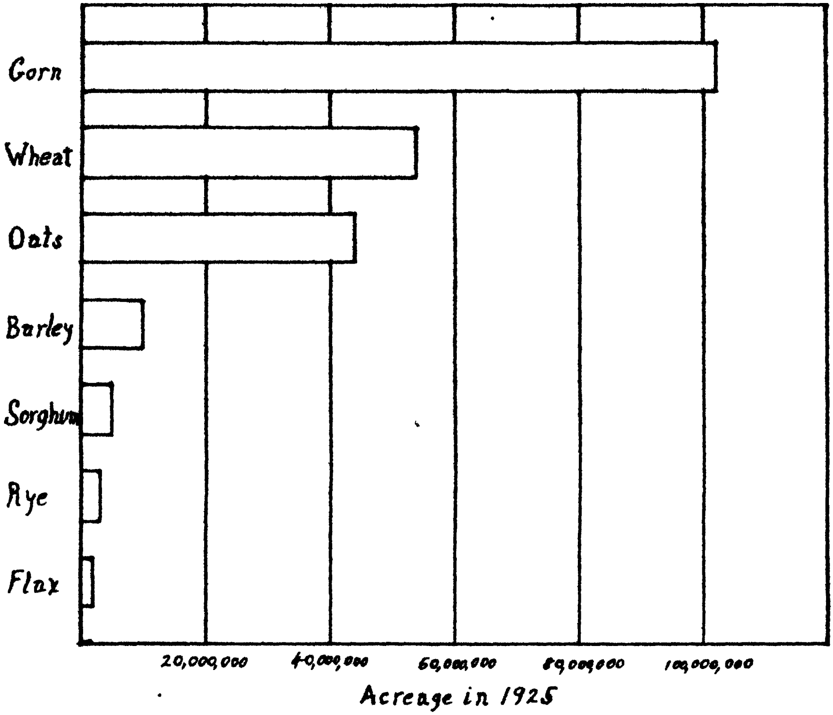

FIG. 1.—The bar diagram. This type of diagram is suitable for illustrating discontinuous variations.
Data taken from U. S. D. A. Yearbook for 1926.

JOURNAL of this Society. The bar diagram, however, will be found quite useful in illustrating discontinuous variations.

The acreage planted to different grain crops in 1925, as illustrated in Fig. 1, represents a series of discontinuous, distinct entities. One cannot start from corn and by a series of minute, continuous steps or gradations pass to wheat, for example. Hence, in this case, it is appropriate to represent the different grains graphically by means of physically separate bars, and it would be bad practice to connect the ends of the bars with a line.

With continuous variates the case is quite different. For example, it is possible to pass continuously by successive, unbroken, small steps from a yield of 15 bushels of wheat per acre to one of 25 bushels per acre in a comparison of different cropping systems, and such phenomena may be represented graphically by continuous lines. At least four types of diagram are available for representing continuous variations, namely, the histogram, the frequency polygon, the integral curve, and the triangular diagram.

The histogram is regarded by statisticians generally as the most accurate method of representing frequency distributions graphically where it is desired to show the exact numbers in each class. The frequency polygon, on the other hand, shows the general trend of variation, and serves as an excellent method for comparing different strains, varieties, etc. In the histogram the class limits are laid off on the abscissal axis as usual, and the frequencies over each abscissal element are given as the areas of rectangles erected on these base elements. So long as the sizes of classes into which the material is grouped are all equal, then obviously the heights of the rectangles will be proportional to the frequency. Fig. 2 is a histogram representing the variation in height of normal corn plants in a study of the inheritance of dwarfing in maize.[4] The end points of the several

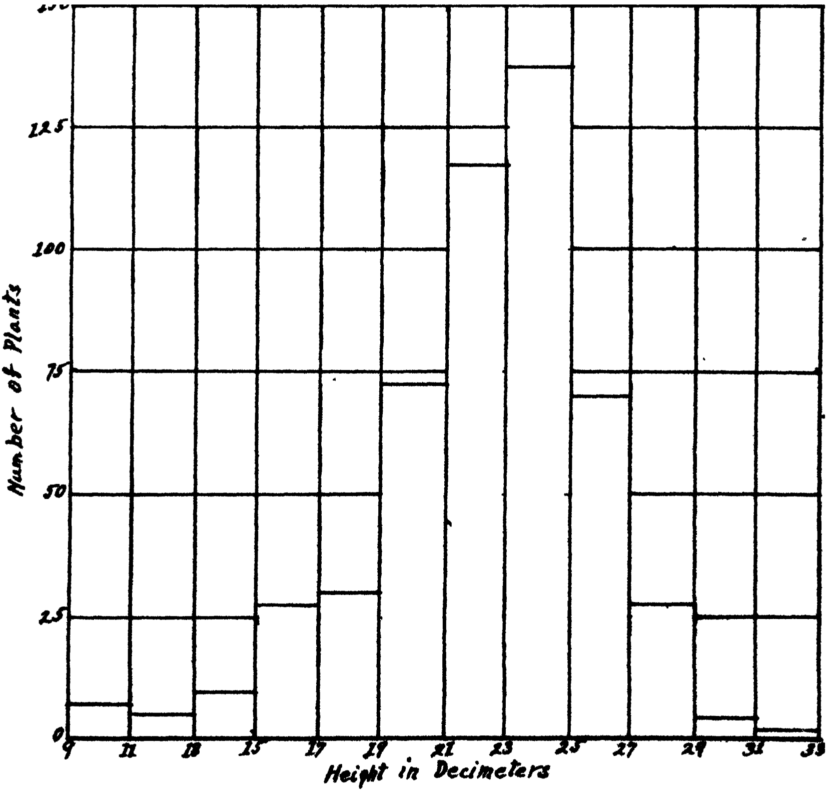

FIG. 2.—The histogram, best adapted to the graphic representation of the exact numbers involved in each class of a frequency distribution.

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[4] Data taken from paper by J. H. Kempton on "Inheritance of Dwarfing in Maize." *In* Jour. Agr. Res., 25: 297–322. 1925.

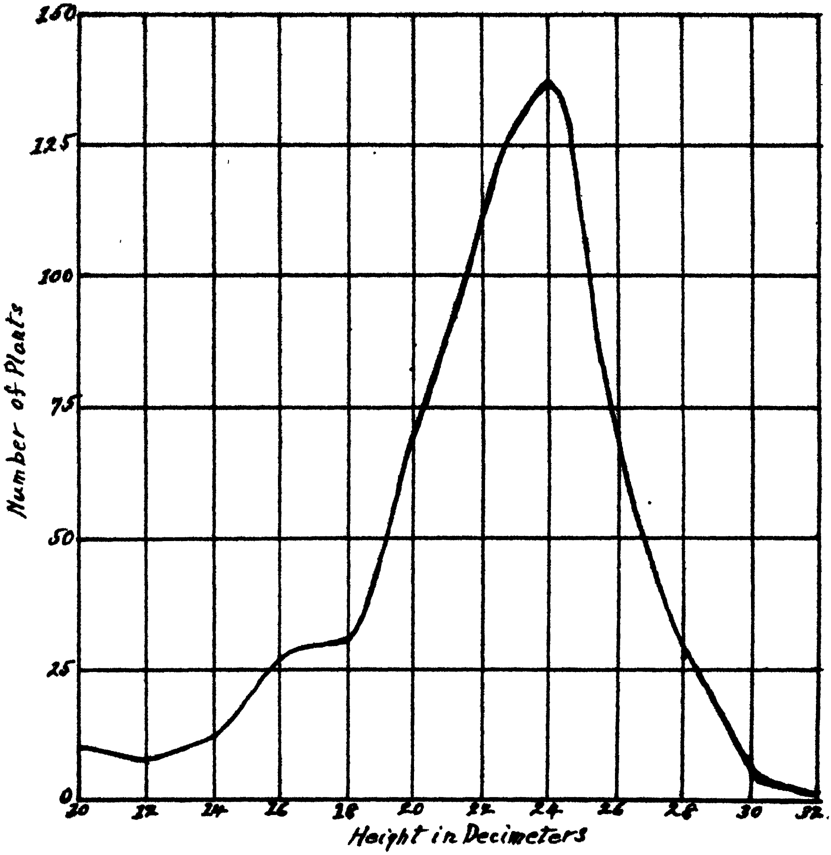

FIG. 3.—The frequency polygon constructed from the histogram shown in Fig. 2. An excellent type of diagram for a general comparison of overlapping frequency distributions.

classes are shown on the abscissal scale and the number of plants, or the frequencies, on the scale of ordinates.

But another way of expressing these relationships, especially if the question of type is involved, is by means of the frequency polygon. The frequency polygon shown in Fig. 3 is the result arrived at by assuming that the total frequency in any given class, such as 9 to 11 decimeters, is concentrated at the center of that class. The ordinates of height are then plotted in proportion to the frequencies supposed concentrated at these midpoints. Fig. 3 is a frequency polygon constructed from the histogram shown in Fig. 2.

The frequency polygon may be used in place of the histogram where the object is to give a general picture to the eye of a series of overlapping frequency distributions.

Another form of diagram is the integral curve, or accumulated diagram of frequency, in which the frequency is successively accumulated, class by class, from the lower range on rather than plotting the value of each single frequency as in the types of diagrams described above. This form of diagram, illustrated in Fig. 4, shows the number of normal corn plants in the breeding experiment under consideration which have attained a height greater or less than any assigned value. This property of the integral curve is often quite useful in facilitating quick comparisons or computations.

Also, by constructing a percentage scale on the right-hand margin of the diagram with the absolute scale of frequencies on the left-hand margin, the diagram will show the relative as well as the absolute accumulated frequencies of height. The advantages of this form of diagram are at once apparent, obviating as it does the necessity of computing percentages.

Spot maps (Fig. 5) or shaded maps are sometimes useful devices for illustrating the geographic distribution of things or events, and occasionally find a place in the JOURNAL of the American Society of

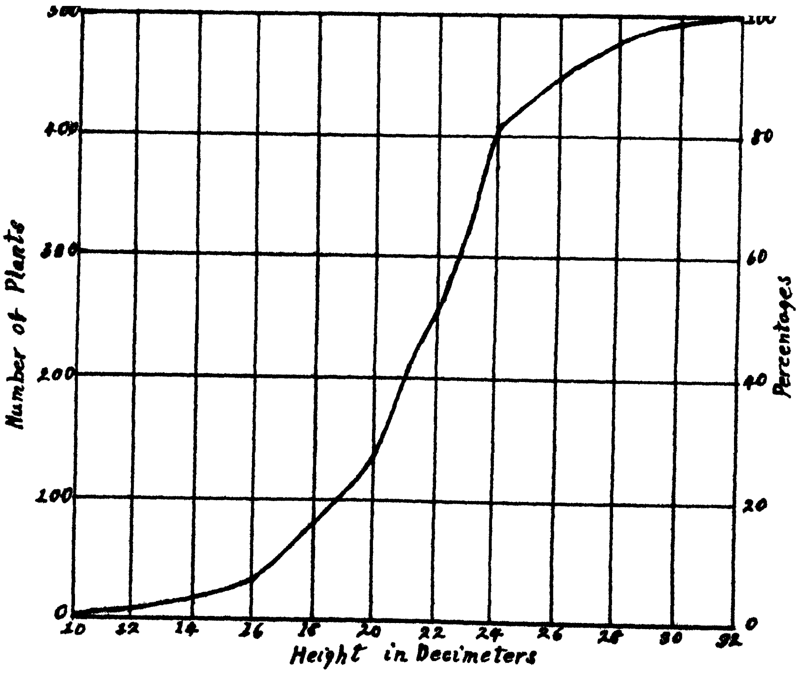

FIG. 4.—The integral curve, or accumulated diagram of frequency. A useful device to facilitate quick computations or comparisons.

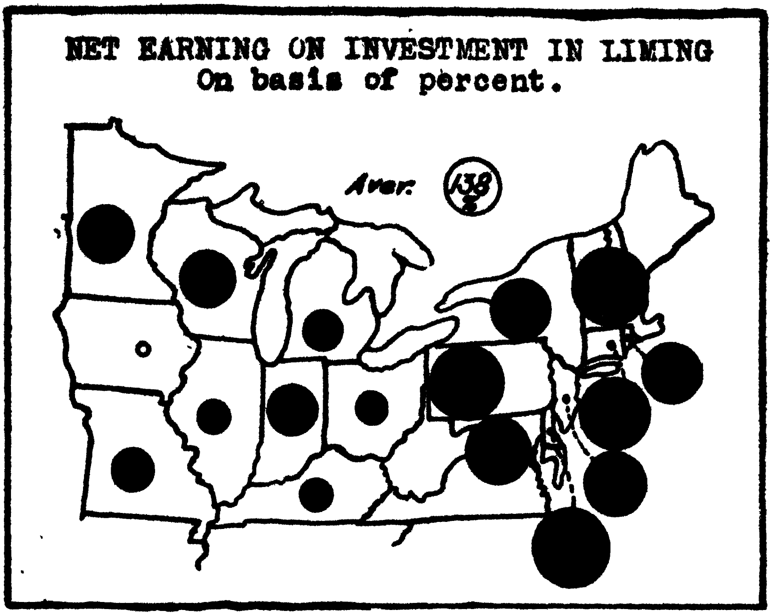

FIG. 5.—Spot map, useful for visualizing geographic distributions.

Agronomy. Excellent examples of the use of this type of diagram will be found in the Year Books of the U S. Department of Agriculture and in the Atlas of American Agriculture.

Trends of events or things with reference to time may occur in cycles or may be non-cyclic. Cyclic trends, such as yearly precipitation or temperatures, may be readily shown by a simple line diagram on ordinary arithmetic grid or by means of polar co-ordinates. Non-cyclic trends, such as diminishing yields of various crops over a period of years on soils receiving no fertilizer elements, also may be represented graphically by means of line diagrams on arithmetic grid. However, when a comparison is made of things differing materially in the magnitude of the numbers involved a better picture will be obtained by means of diagrams constructed on so-called arithlog grid, also known as "ratio charts." The ruling in the arithlog grid is such that the abscissal scale is graduated in arithmetic progression, while the scale of ordinates is divided in proportion to the logarithms of numbers in arithmetic progression. Such ruling is believed to give a much truer picture of the relation of non-cyclic events than a simple line diagram on ordinary arithmetic grid.

Although having no bearing on agronomy, Figs. 6 and 7, taken from Dr. Pearl's book, illustrate the difficulties that one may encounter in comparing non-cyclic trends on regular arithmetic grid. Fig. 6 shows a portion of a chart intended to illustrate the comparative death rates from tuberculosis and typhoid fever for the period of 1900 to 1910. On regular grid the death rate from tuberculosis apparently declined more than that from typhoid fever. Plotted on arithlog grid, however, as in Fig. 7, it will be seen that the reverse was true, and that the death rate from typhoid declined much more than that from tuberculosis. The distorted picture obtained with the common grid is due to the fact that the death rate from tuberculosis involves relatively large numbers as compared with that from typhoid. This demanded the use of large numbers on the scale of ordinates and a "flattening out" of the smaller numbers for the typhoid death rate as a consequence.

A discussion of graphic methods for the interpretation of agronomic data would not be complete without mention of the triangular diagram.

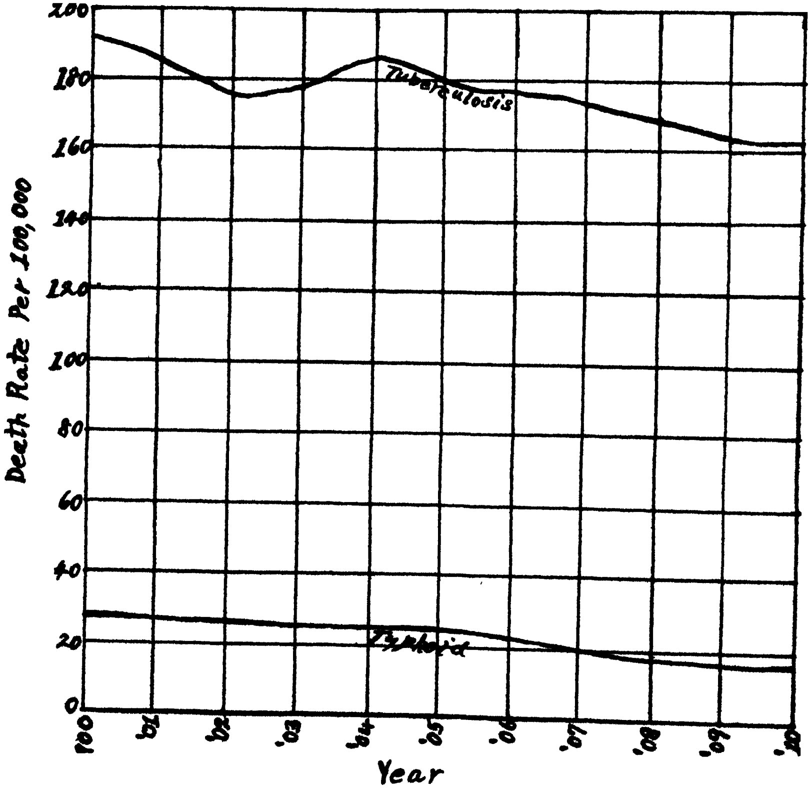

FIG. 6.—A comparison of non-cyclic trends on regular arithmetic grid.

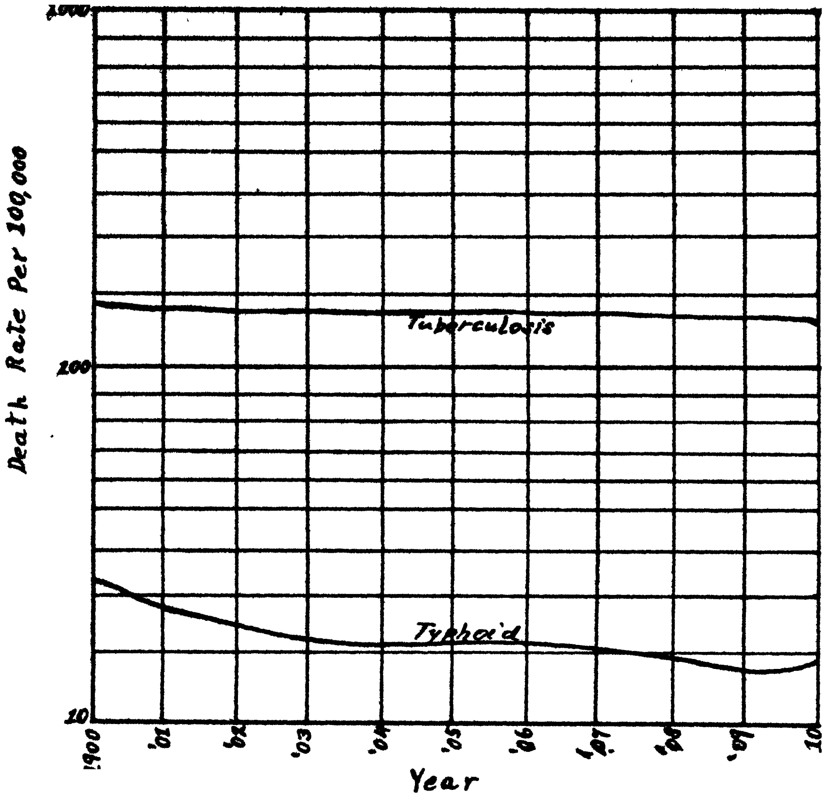

FIG. 7.—A comparison of the non-cyclic trends shown in Fig. 5 when drawn on arithlog grid.

This diagram, used so effectively by the physical chemist, has been admirably adapted by Schreiner[5] and others to the interpretation of field and pot experiments. The triangular diagram serves not only as a means of interpreting experimental results, but is also utilized to show the arrangement or distribution of fertilizer or other treatments in the field or greenhouse.

Other types of diagrams, such as the hexagonal chart and nomograms, should receive mention in passing because of their usefulness in facilitating computations in the laboratory or class room. However, they would seldom find a place in the pages of the JOURNAL in the interpretation of experimental results.

With this brief outline of graphic forms, let us turn now to consideration of the practical applications of graphic presentation of

[5] SCHREINER, OSWALD. U. S. D. A. Bur. of Soils Bul. 70. 1910.

experimental data. Some progress has been made toward the formulation of certain broad principles which should govern the construction of graphs; and while unreasonable standardization is not desirable, much good may be accomplished by following what has come to be regarded as good practice by those who have given the matter critical consideration.

In 1915, a joint committee representing engineering, statistical, economic, biologic, and other societies, under the chairmanship of Dr. W C Brinton, drew up a set of recommendations which may be briefly summarized as follows·

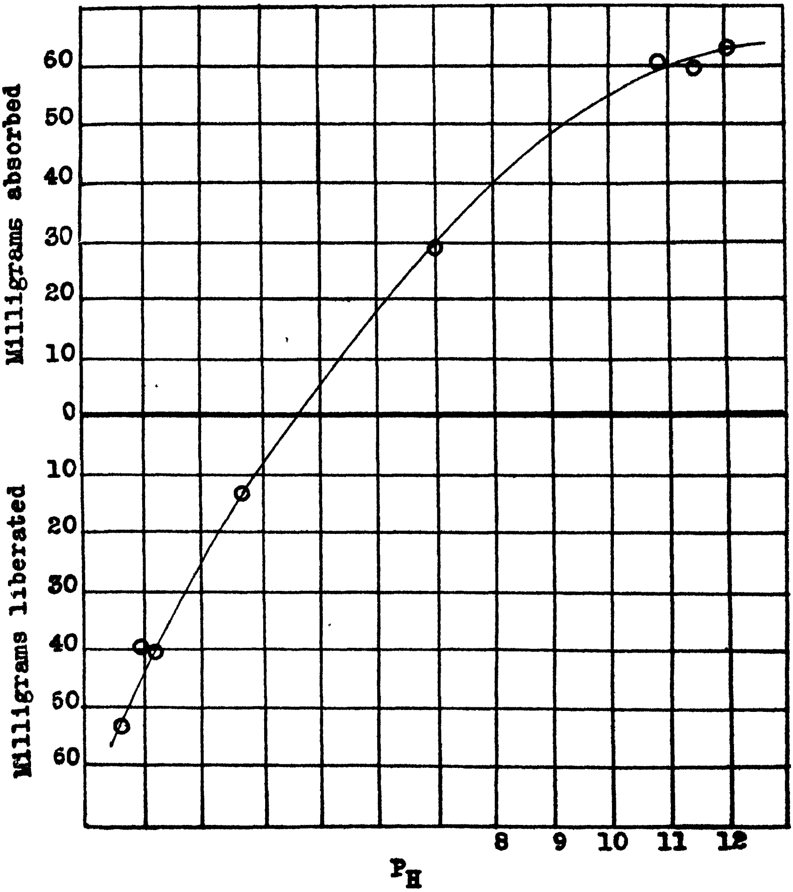

FIG. 8.—A diagram with several good points and one weakness. The arrangement of the data, the broad line for the zero point, designation of the points of observation, and the wide spacing between the grid lines commend this chart. The curve line, however, should be a heavier line than the grid lines.

1. Represent quantities by linear magnitudes rather than by areas or volumes, as presentations read from only one dimension are least likely to be misinterpreted.
2. The general arrangement of a chart should proceed from left to right (Fig. 8).
3. Figures for the abscissa should always be placed at the bottom of the chart, with a scale at the top also, if needed (Fig. 8)
4. Figures for the ordinate should always be placed at the left of the chart, with a scale on the right, if needed (Fig. 8).
5. All lettering and all figures on a chart should be placed so as to be read from the base or from the right-hand edge of the chart (Fig. 8).
6. For most charts and for all curves the independent variable should be shown on the abscissa (Fig. 8).
7. As a general rule, the abscissal scale for curves should read from left to right and the scale of ordinates from bottom to top (Fig. 8).
8. For curves drawn on arithmetically ruled paper the scale of ordinates should be so selected, whenever possible, that the zero line will show on the chart (Fig. 8).
9. Make the curves with much broader lines than the co-ordinate ruling so that the curves may be clearly distinguished from the background (Fig. 9).
10. The zero line of the scale of ordinates for a curve should be a much broader line than the co-ordinate lines (Fig. 8).
11. If the zero line of the scale of ordinates cannot be shown at the bottom of the chart, the bottom line should be made slightly wavy to indicate that the field has been broken off and does not reach to zero (Fig. 9).
12. When the scale of a curve chart refers to percentages, the line at 100% should be a broad line of the same width as the zero line.
13. If the abscissal scale for a curve begins at zero, the vertical line at zero (usually the left-hand edge of the field) should be a broad line.
14. When the abscissal scale expresses time, the lines at the left- and right-hand edges of a curve chart should not be made heavy, since a chart cannot be made to include the beginning or the end of time (Fig. 9).
15. Where charts are to be reproduced for printing, only such co-ordinate lines as are necessary to guide the eye should be used. Lines ¼ inch apart are generally sufficient for this purpose (Figs. 8 and 10).
16. When curves are drawn on logarithmically ruled paper, the bottom line and the top line of the chart should each be at some power of ten on the scale of ordinates (Fig. 7).
17. Whenever possible, include in the chart the numerical data from which it is made, but if the numerical data cannot be included in the chart, it is well to show it in tabular form accompanying the chart.

18. In curves representing a series of observations, it is desirable, whenever possible, to indicate clearly on the diagram all the points representing the separate observations (Fig 8).
19. Make the title of each chart so complete and so clear that misinterpretation will be impossible.

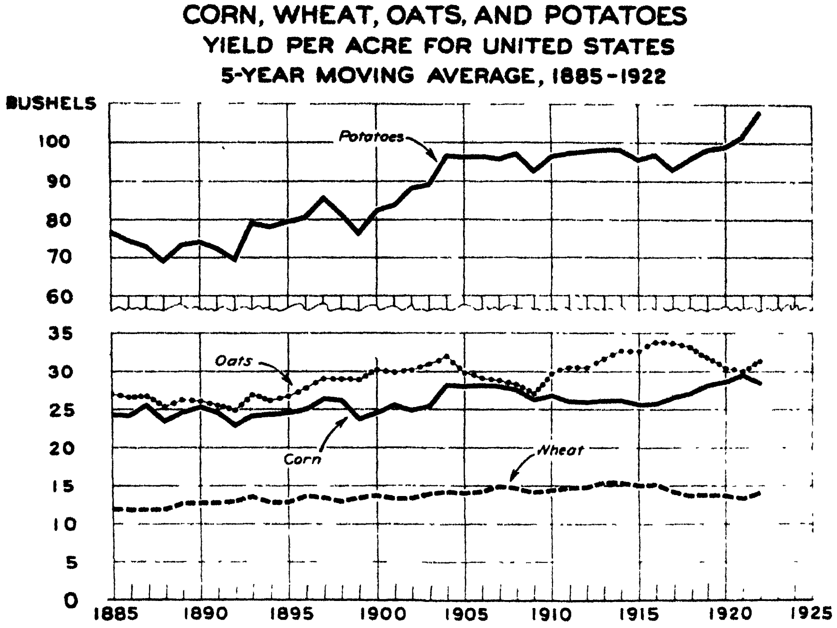

FIG. 9.—A good example of a broken field. This device is particularly useful where the field does not reach to zero. An excessive number of grid lines is avoided in this chart by means of the short lines for each year of the five-year intervals.

Supplementing these recommendations, the writer offers the following suggestions for the mechanical make-up of charts for the JOURNAL of the American Society of Agronomy.

1. The selection of paper for making charts for reproduction in the JOURNAL should be governed by the points to be brought out in the illustration. For example, if it is not necessary to show all the co-ordinate ruling of specially designed graph paper, much more satisfactory results will be obtained by using plain white paper of good quality or blue-line cross-section paper with the necessary vertical and horizontal lines drawn in by hand so as to avoid obscuring the curves by an excessive number of grid lines.

2. If it is necessary to show all the co-ordinate rulings, it should be remembered that blue does not photograph for reproduction, and that paper should be used which has the ruling printed in green,

brown, black, or red. Incidentally, scientific supply houses, if stimulated by demand, might be encouraged to produce grid paper with the heavy rulings in some color that would reproduce and with the intermediate rulings in blue, an arrangement which has some very obvious advantages to anyone who has constructed many graphs.

3. Of even greater importance than the wise choice of paper is the use of black, indelible ink, such as India ink, for all lettering, curves, and lines that are to be reproduced. *Typewritten figures and letters are not satisfactory.* Neglect to use suitable ink is probably the commonest fault to be found with copy submitted to the JOURNAL.

4. The careful lettering of charts will be amply repaid in the greatly improved appearance of the printed copy. Many charts are spoiled by careless lettering.

5. The author should give careful consideration to the reduction in size to be made when the chart is reproduced in the JOURNAL. The JOURNAL page is 4¼ by 7 inches, and good typography demands that all matter be kept within these limits. Therefore, unless otherwise instructed, the editor automatically marks all copy for reduction

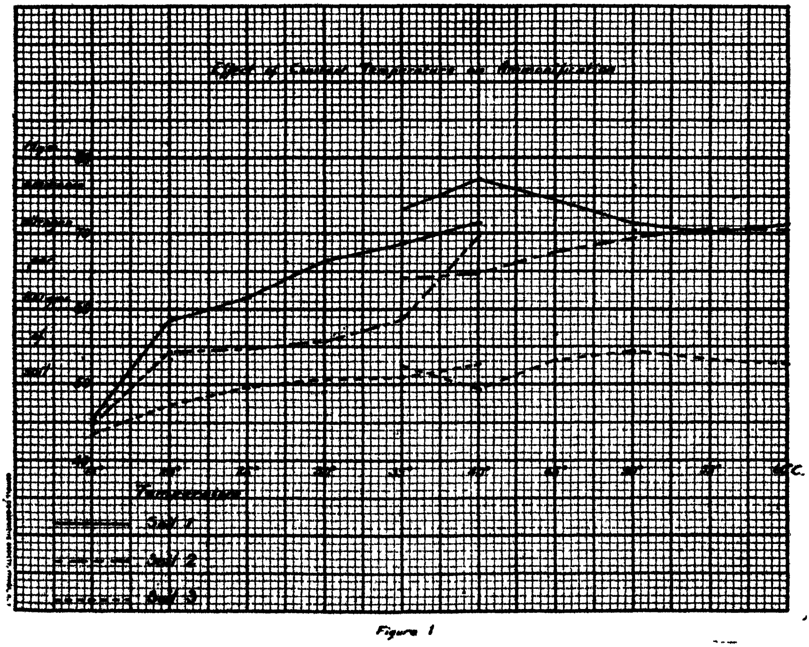

FIG. 10.—The disadvantages of an excessive number of grid lines. The heavy lines would have been ample in this case and the figures, curves, and lettering would have been more legible. Another defect of this chart is the placing of the legend in the diagram, a defect illustrated also by Figs. 5 and 9.

to fit the JOURNAL page. Occasionally, however, the author is disappointed in the results obtained; and to avoid misunderstanding and disappointment, it is suggested that wherever a chart or series of charts have been drawn to a special scale for reproduction in certain definite proportions, a statement to this effect be submitted with the copy. In any event, the size of the JOURNAL page should be kept in mind so that the finished graph will neither exceed the prescribed dimensions nor be materially less than 4¼ inches wide.

6. With further reference to reduction, it is a curious fact and one that should be reckoned with in preparing charts for the photo-engraver, that in reducing line drawings the actual strength of the line, that is its width, does not diminish in the ratio of the reduction, and beyond a certain point does not diminish at all. Therefore drawings which are to be greatly reduced, say to ¼ or 1/5 their original diameter, must be made open and with the lines and dots far apart, otherwise the lines and dots will run together in the cut, producing a confused, indistinct appearance. However, all lines that are to be reproduced should be drawn sufficiently heavy to stand some reduction, although generally copy submitted to the JOURNAL errs in the direction of excessively heavy lines.

To the photo-engraver, the word "reduction" always means diameter or base-line reduction and not actual size. One-half reduction means one-half the diameter which means that the original area of the drawing or picture will be reduced to one-fourth. Therefore, to mark a drawing "reduce ¼" and "reduce to ¼" does not mean the same thing. "Reduce ¼" means that the finished cut will be ¾ the diameter of the drawing, while "reduce to ¼" means that the cut will be ¼ the original diameter

7. Allowance must also be made for the legend or caption to the chart in marking the original drawing for reduction. As already stated the type page in the JOURNAL is 7 inches long, and save for exceptional cases, this should cover the chart and its caption. If an unusually long caption is required, allowance should be made in planning for the reduction of the drawing.

8. Finally, the desirability of adequate captions for all charts cannot be too strongly emphasized. The chart with its caption should be complete in itself, since a mere numbering of the charts as text figures leaves the reader in a quandary as to the significance of the illustrations. It is suggested, too, that all captions be supplied apart from the drawings to be set in type rather than to be made a part of the photo-engraving. This is largely a matter of style which the editors believe adds to the typographical appearance of the JOURNAL.

5. MAKING PHOTOGRAPHS FOR ILLUSTRATION IN PUBLISHED ARTICLES[1]

C. H. HANSON[2]

The advancement of the science of agronomy as well as popular interest in and support for it would be appreciably enhanced by a greater and more wisely directed use of photography. In its legitimate field, the camera can not be surpassed as an accurate, convenient, and economical instrument for the recording of agronomic data and of farm scenes and practices of interest to the agronomist and the reader of his articles.

The use of illustrations always adds appreciably to the expense of printing and therefore it is fair to ask, "When are we justified in illustrating our articles?" Only when we have suitable photographs that will not only direct attention to and arouse interest in our article but will also explain or clarify the text. The pictures must tell clearly some definite worth-while story and reenforce and help to fix the impression made by the printed word.

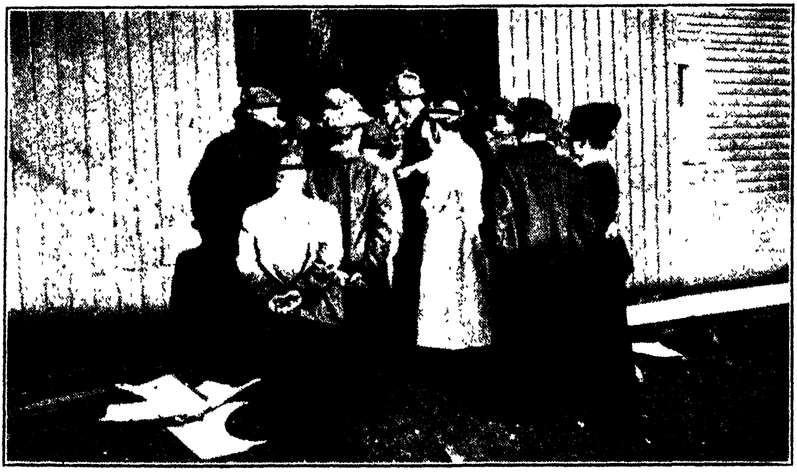

FIG. 1.—A picture which does not tell a definite story.

There is no use of bewailing the fact that much of our photographic work is a waste of time, money, and effort. Our duty is that of trying to correct this condition. It is not much of an exaggeration to say that the value of pictures is almost in direct proportion to the amount of well-directed effort put forth in the planning as well as the taking thereof. If we would place our cameras on firm tripods and carefully study our subjects on the ground glass *before* making our exposure, the results would greatly improve. Thoughtless snapshotting has no place in the photography of the writer of illustrated articles on agronomy. Neither should we approve of the practice of writing articles and thereafter looking around for photo-

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[1] Paper read as a part of the symposium on "Publication of the Results of Agronomic Research" at the meeting of the Society held in Washington, D. C., November 18, 1926.

[2] Specialist in Visual Instruction, Office of Cooperative Extension Work, U. S. Department of Agriculture, Washington, D. C.

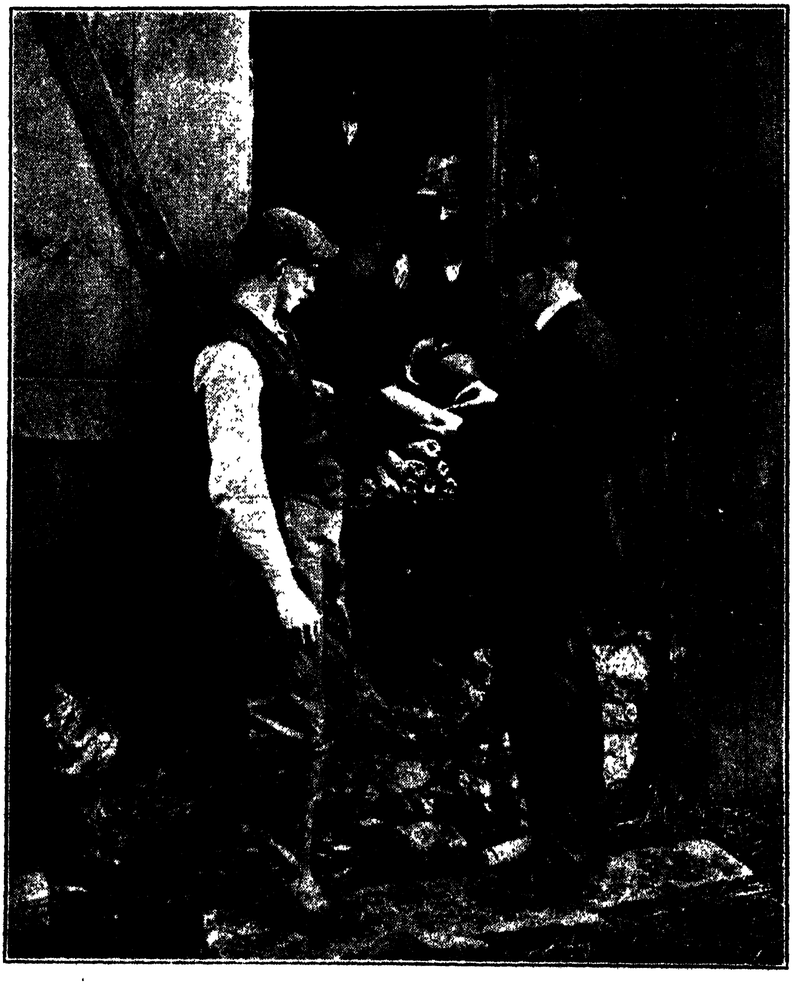

FIG. 2.—A picture which tells a definite story.

graphs to make them look interesting. High-class illustrated articles, like high-class clothes, are made to order. Let us now pass to some of the practical problems of outdoor photography.

Many pictures are a failure because they do not tell a definite story as shown in Fig. 1. In this instance, as is so often the case, it is impossible to make out what the photographer wanted to illustrate. Before a person can succeed in picture making he must first know what constitutes a good picture and, second, must have a clear-cut and definite purpose in mind before making the exposure. He must visualize the finished picture. Note the improvement in Fig. 2. It tells its story at a glance. Its value is further enhanced by its simplicity and pleasing arrangement. It tells just one story. One of the most frequent mistakes of the novice is that of including too much irrelevant material in a picture. Too often a photograph contains two or more pictures—one should be the limit. This is a fundamental principle in modern art.

The great majority of successful pictures of groups are more or less posed. When taking such groups, remember that the surroundings, dress, and poses must be natural.

Clean, white starched collars and a nice business suit are much out of place on a thresher. Let all of the elements of the picture combine to make one harmonious unit. The accomplishment of this is usually simplified by having the interest of the entire group concentrated on one thing within the boundaries of the picture space. Pictures of idle groups lined up looking at the camera have only personal and temporary interest. They lack appeal and publishers do not want them.

The value of pictures for popular use can be greatly increased by introducing human interest. Remember that placing a human being into the view is not synonomous with introducing human interest. How introduce human interest? First, when possible, by having in the view one or more persons with whom your readers are personally acquainted or in whom they are interested; second, by showing your group actually doing something in which your readers are interested; and, third, by putting as much action and life into the picture as possible. (See Fig. 3.) Do not forget that good composition plays no small part in the successful making of this type of picture. The better the selection and arrangement of the subject, the more realistic and practical the story told, and the more action and life put into the group, the more interesting and convincing the picture.

The one feature which possibly more than any other one thing distinguishes the work of the truly successful photographer of agricultural subjects is the selection of his point of view. Too much

FIG. 3.—Pictures showing action usually have the greatest appeal.

stress can not be laid upon the importance of placing the lens in the best position to tell the story What is meant can be easily seen in the pictures taken to show the construction of implements. In Fig. 4 we have an example of a picture of a weed cutter taken from the wrong point of view; in Fig. 5, a photograph of a clod crusher taken from a well-chosen point of view.

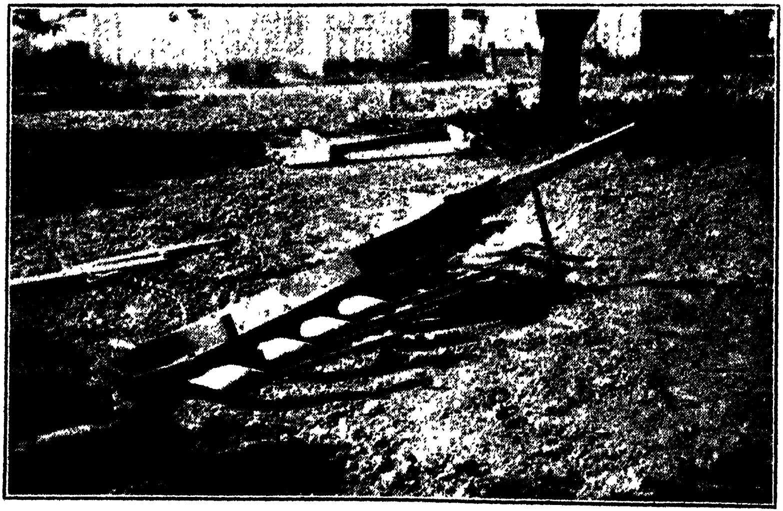

FIG. 4.—Photograph of a weed cutter taken from a poorly chosen point of view.

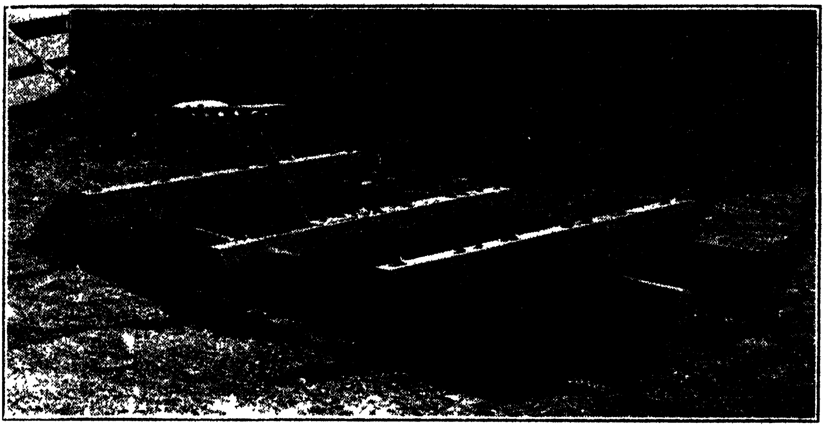

FIG. 5.—Photograph of a clod crusher taken from a well chosen point of view.

A general rule that should not be departed from is to view the subject from every available position from which such a subject is normally viewed. After selecting the one position which most clearly shows the thing which it is desired to record, place the lens as near as possible in that position. Every one is familiar with the fact that moving the camera left or right of the subject greatly affects the result, but many overlook the fact that a difference in the height of the lens from the ground or the distance of the subject from the camera may also greatly affect the value of the picture. A little

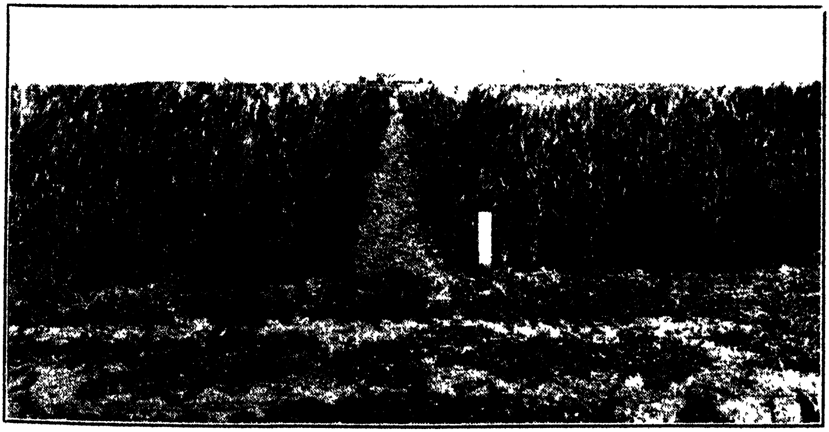

FIG. 6.—Photograph of a plat taken from too low a point of view to show the plat to advantage.

observation of plats and a study of photographs thereof should quickly convince one that many a field photograph has failed of perfection because the lens was not placed at the proper height from the ground as shown in Fig. 6. Compare this with the picture in Fig. 7 showing a better point of view.

When a series of pictures of plats in an experiment are photographed for comparison, special care should be taken to see that the respective plats are taken at the same distance, from the same relative points of view, and with the same lens or one of the same focal length. If possible it would be well to have them taken under like light conditions. We find that pictures of this type are among the most convincing and useful in our entire collection and therefore feel that care should be exercised to make them strictly comparable.

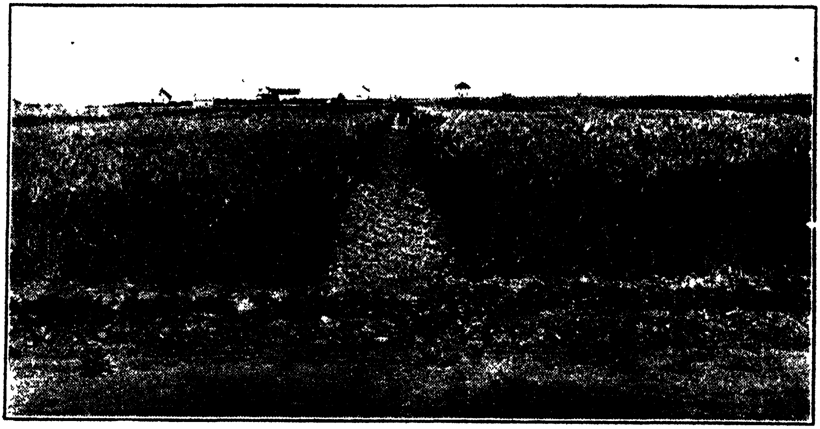

FIG. 7.—Photograph of a plat taken from a well chosen height.

The scientist's business is to search for the truth; hence he must refrain from placing his camera closer to his favorite plat than to the check. The size of the image formed by a given lens is proportional to the distance of the lens from the object. This must be kept in mind if acceptably accurate records are to be made for comparison. For example, if a series of shocks of corn from different plats are photographed, the shocks at the greatest distance will of necessity appear dwarfed. Another phase of this subject is exaggerated perspective or foreshortening in photographing a single object. In such cases the portions nearest the camera are too large in proportion to the parts farther away. This is most often noticeable in pictures of horses and cattle taken "head on" at close range. Such distortion can be avoided very largely by equipping your camera with a lens having a focal length about 1½ times the length of the plate or film. But this remedy has its disadvantages which will be discussed later. The important thing to remember is that exaggerated perspective is due to the camera being too close to the subject. The ideal solution of the problem of obtaining both good perspective and adequate size of image in a negative is to have a battery of lenses of varying focal lengths that will enable one to choose the proper focal length of lens for the selected point of view. This need not be as expensive an equipment as it sounds. One good well-chosen convertible lens (which may be called three lenses in one) will often serve this purpose very well. Such equipment has the further advantage of being able to include only what is wanted.

Men vary so in height, and there are such variations in the positions taken by them when used as standards of measure when photographing crops, that it is to be questioned whether it is not just as well for all ordinary purposes to take such pictures without a person standing in the plat or field. If it seems desirable or advisable to have some standard of measure in the view then judgment should be used in the selection and placing of it (Fig. 8). All nonessentials should be excluded. Place the standard of measure, whatever it may be, at one side in an inconspicuous position so that it will compete as little as possible with the principal subject of the picture.

Many a picture is ruined because of an inappropriate background. Under no circumstances should the background be of such a character as to attract attention away from the real subject of the picture (Fig. 9). The simple, quiet, and pleasing background, which will aid in centralizing the interest in the principal object in the picture, is the type to be sought (Fig. 10). The background may also serve the very useful purpose of supplying needed contrast to make an object stand out clearly. A photograph in which the important object blends into the background is hopeless for half-tone purposes (Fig. 11).

The choice of background will, of course, depend upon the character of the subject. When a dark background is wanted there is no simpler method than to make use of an open doorway (Fig. 12). Windows in the view should be covered and prominent objects like machinery should be removed from the foreground.

Fig. 13 suggests ways and means of handling closeup views. Note that the old gentleman was wearing a black coat, but that in the brilliant sunshine it looked grey. To secure a darker background for the soybean nodules, he was put into such a position as to cast a

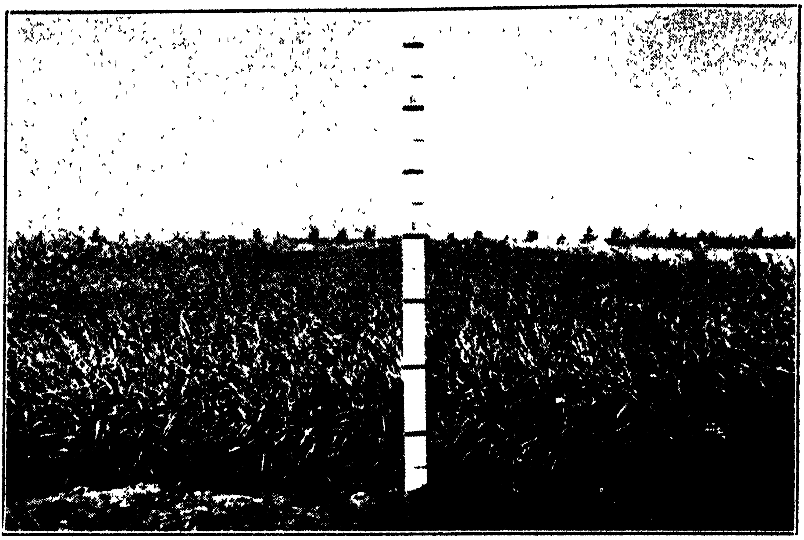

FIG. 8.—A poorly placed standard of measure. It would be better placed if near the edge of the picture and far enough back to show the height of the crop.

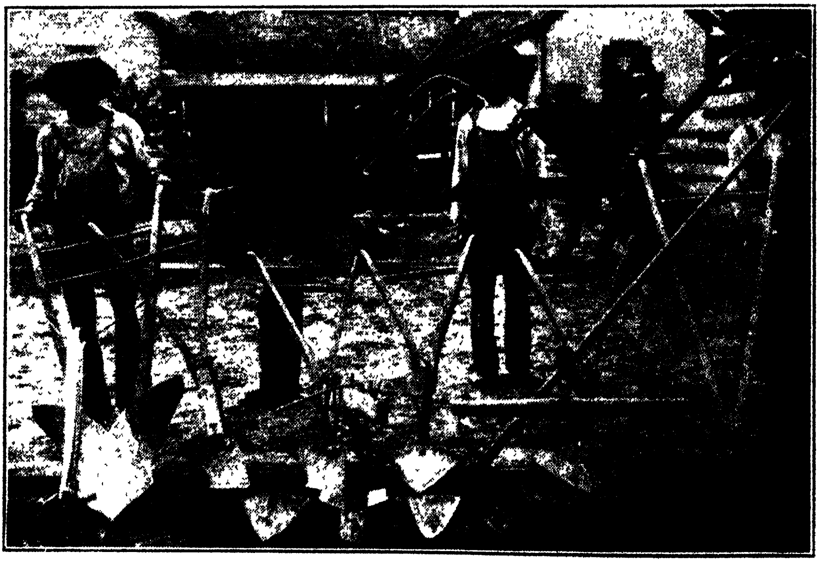

FIG. 9.—These implements do not stand out clearly because of the confusing background.

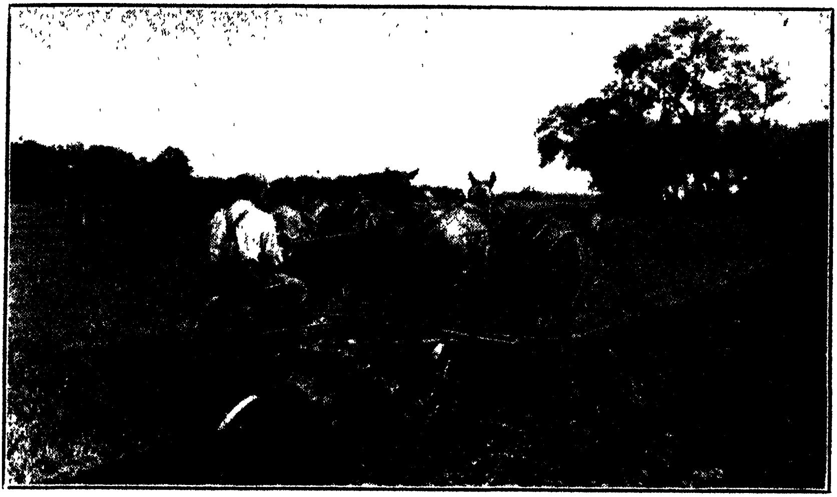

FIG. 10.—A picture having pleasing lines and a good background.

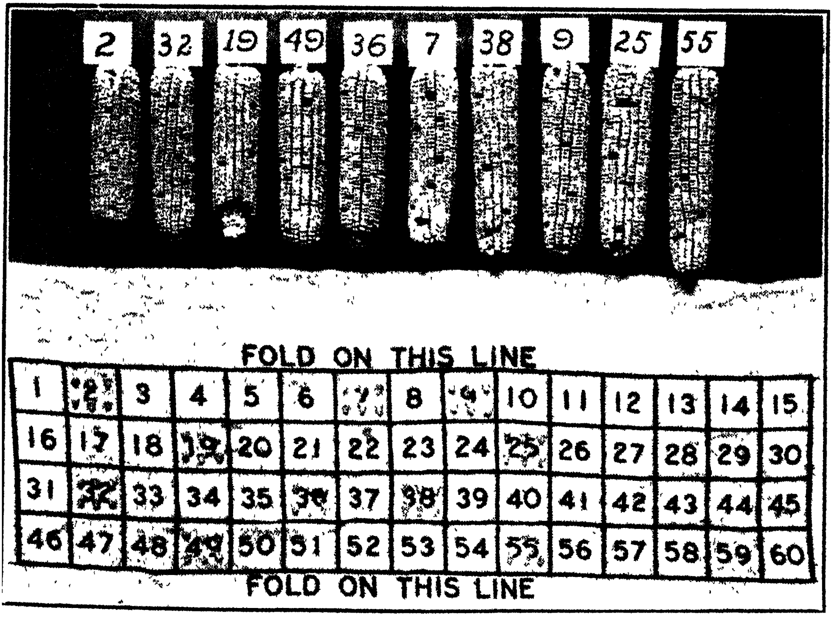

FIG. 11.—Objects do not stand out clearly unless they contrast sufficiently in tone or color with the background.

shadow across his left shoulder. The roots with their nodules were then held a short distance from the background and the exposure was made with a long-focus lens. There is only one thing to suggest about backgrounds for contrast plats and that is that the same objects should, if possible, appear in the background of the entire series of pictures.

For field purposes a white sheet or cloth is frequently used as a background for a few or individual plants (Fig. 14). If one does not object to the artificial appearance of the finished picture, white cloth

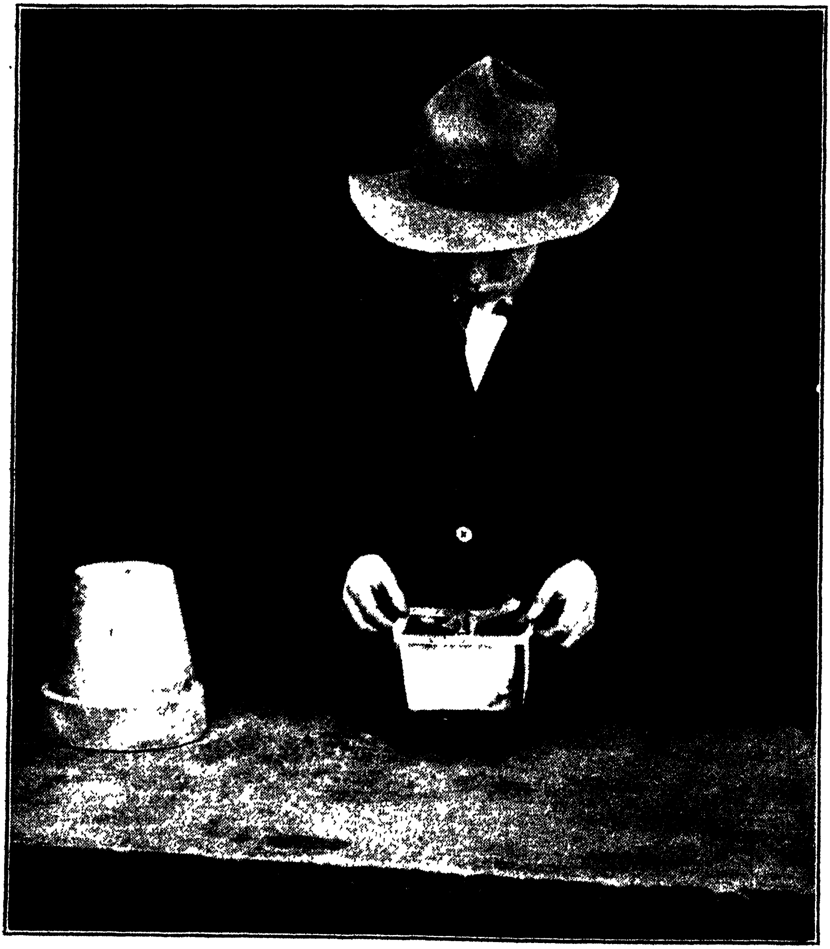

FIG. 12.—The open doorway of a rather weakly illuminated interior is a good place to photograph subjects for which a dark background is desired.

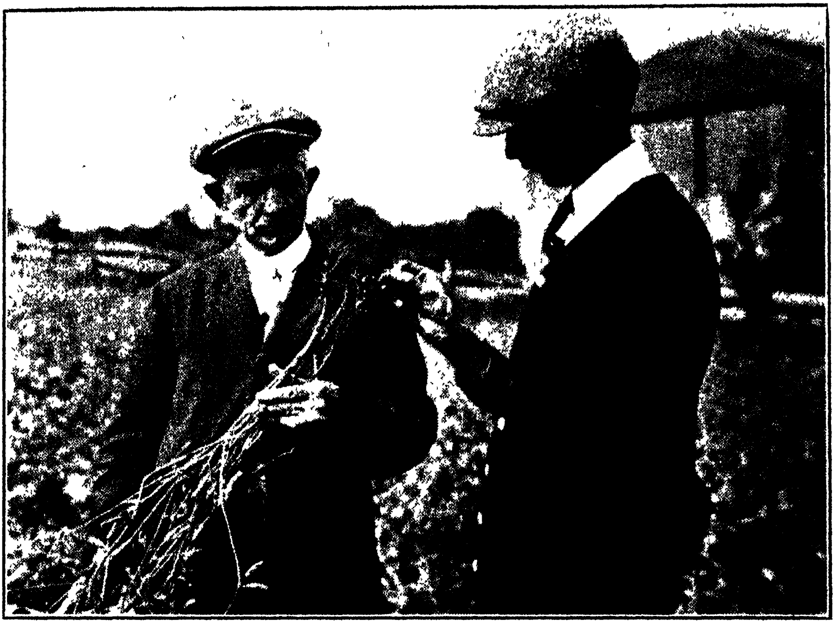

FIG. 13—The shadow of the man's shoulder aids materially in making the soybean roots and nodules stand out clearly.

can be successfully used, but it has a number of serious disadvantages. In the practical handling of such material both in transit and in the field one can hardly avoid soiling and wrinkling it. Unless special pains are taken to stretch the cloth evenly, heavy disturbing shadows will be cast upon the screen by the folds and wrinkles in the cloth. The ugly line across the base of the plants produced by the lower edge of the screen is also very objectionable. In addition to these disadvantages the cloth is heavy and hard to handle in windy weather.

When using cloth for backgrounds try to select a time of day when the desired view can be gotten without the plants throwing shadows upon the screen. The proper tone of background to use will, of course, depend upon the character of the subject. Frequently a neutral tint is very useful. If a background of the desired tint is not available, it is worth remembering that the effect can be appreciably modified by merely changing the position of the background. By holding the screen in a perpendicular plane and swinging it to the left or right, the amount of direct sunshine falling upon it can be modified. By tilting the screen away from the perpendicular, the amount of skylight falling upon it can be modified. The important thing is to learn to observe the lighting and character of both subject and background before making the exposure. No one will ever make any marked success in photography until he begins to think of pictures in terms of light and shade.

The difficulties which we have just discussed can be very largely eliminated by the use of a bobbinet background, if sufficient care be taken as to the relative positions of the camera, object, and sun. In the photograph shown in Fig. 15 a light brown bobbinet background was used. The Office of Cotton, Rubber, and Other Tropical Plants of the Bureau of Plant Industry has been very successful in the use of this material, and I am privileged to quote from an unpublished manuscript of that office on the manipulation of bobbinet backgrounds.

"Allowing the sun to shine directly upon the background makes the latter appear nearly white and opaque, and confusing shadows are thrown by the plants, but if overhead or along the rows and slightly in front, the screen is transparent, showing the plants in the field

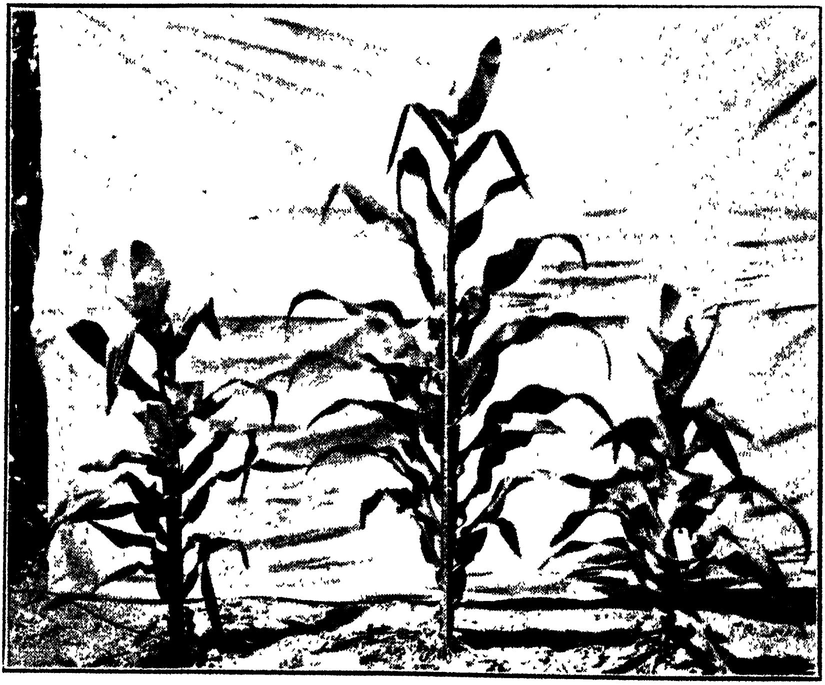

FIG. 14.—When photographing large plants outdoors it is very difficult to produce an even and pleasing background with white cloth.

beyond but these latter sufficiently lightened to prevent confusion with the object plants.

"This material, being light and porous, offers little resistance to the wind, does not wrinkle easily, and the neutral color helps to diffuse the objectionable line where the screen touches the ground. Quite often the object has both white and green in its composition, the screen performing equally well for both. If a little extra care is exercised to spread or kick dirt over the lower edge of the cloth the change from ground to screen will be almost unnoticeable.

"Bobbinet can be purchased in the large department stores in three-yard widths. Most of them carry the brownish shades, but

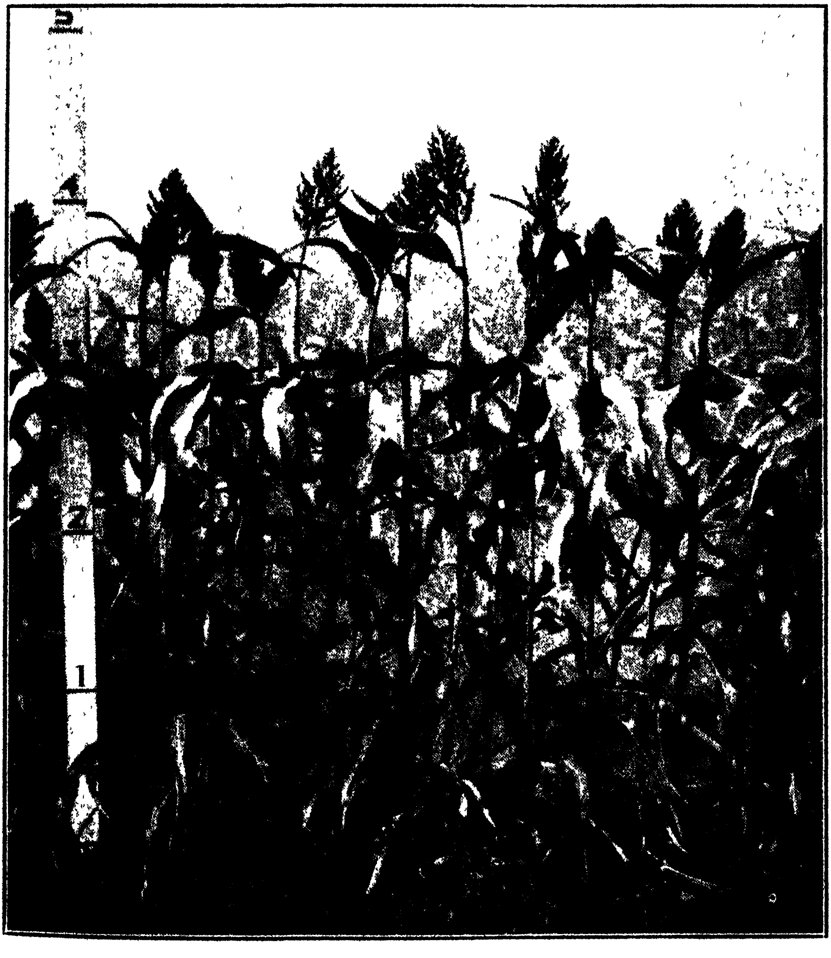

FIG. 15.—An example of the fine results obtained with the aid of a bobbinet background.

white can be secured and easily stained a desirable shade with old tea grounds."

The foreground in outdoor work often contains the most important part of the view being taken and consequently should receive careful attention. Rubbish and nonessentials should be cleared away so that the reader will not have to guess what he is to look at or have his attention drawn away from the designed center of interest. There is no escaping the fact that we defeat our very purpose by giving prominence to nonessentials in our pictures. When photographing plats it is helpful to have the visible edges as well as the spaces between them clear of weeds and clean cut so that the height of the crop will be clearly visible.

Before discussing some of the outstanding technical problems of the plant photographer it seems proper at this stage to digress for a few moments to speak of photographic copy and its preparation for the engraver.

It is self-evident that high-grade half-tones can be made from high-grade photographs only. But what constitutes the ideal print for half-tone purposes? Engravers and publishers seem to be unanimous in their opinion that the best results are obtained from prints made on glossy paper. A highly glossed printing paper reproduces the maximum amount of the detail in the negative and therefore is to be preferred to rough-surfaced paper which can not be used for reproduction without the uneven surface of the paper showing in the half-tone.

The almost universal practice to-day is to use black and white prints on glossy developing paper for half-tone purposes. The developer most generally used is metol-hydrochinon. For best results follow the maker's instructions as to formula for the particular grade of paper being used. Good black and white prints are what is wanted. Keep away from green tones and endeavor to produce prints that have clear shadows. Prints without too much contrast are preferred. To obtain a highly glossed surface and thus increase the sharpness of detail it is common practice to roll the wet prints face down upon a clean and polished ferrotype plate and allow them to dry thereon.

One of the much-disputed questions about prints for reproduction by the half-tone process is, "What is the ideal size of print?" Some engravers will say the 8 x 10; others say the equipment and technic have been improved to such a degree that size of copy is not very important so long as appreciable enlarging is not demanded. The tendency seems to be to lay less stress on size and more on the quality of the copy. If the very best results are to be obtained, however, the photograph of the object should be slightly larger than the half-tone that is to be made from it. Just how much this reduction ought to be can not be given, as this will vary with the copy, but 10 to 25% is usually considered ample. The important things to keep in mind regarding enlarging and reducing in half-tone work are these: If the scale of enlargement is too great there will be a noticeable coarseness and magnification of the imperfections of the copy; if the reduction is too great some of the fine detail will be so compressed as to be lost; if the half-tone is the same size as the copy the imperfections in the copy are usually emphasized slightly. It is evident, therefore, that every effort should be made to produce negatives and prints that are as nearly perfect as good technic can make them.

In general it is preferable to send unmounted and untrimmed prints to the engraver. Each illustration with complete instructions may be placed in an envelope or negative preserver. Another good method is to attach each print to stiff paper or thin cardboard in which incisions have been made for inserting the corners of the photograph. Wire clips should never be used on photographs. The use of arrows in connection with figures to indicate direction of dimensions is a safe means of designating size on copy. Do not give both dimensions of the plate unless it is necessary. It is much safer to give only one dimension and let the other come as it will. Do not attempt lettering or put alterations on photographs—leave this for the artists to do. Instructions regarding such work should not be made on the print itself. A better plan is to attach a sheet of thin tissue to the top edge of the photograph, letting the tissue cover the face of the print, and on the tissue make such notations and marks as may be necessary for the proper instruction of the artist.

Thus we see that the engraver demands a photograph of maximum sharpness and detail and prefers that it be a little larger in size than the half-tone cut. This has a close relationship to the selection of suitable equipment and the technic of using it.

What size of camera to use for field work is a difficult problem. The speaker's personal opinion is that 5 x 7 is the maximum size and 4 x 5 the minimum for serious use. Where conditions permit the 5 x 7 is to be preferred, but to those who find such an outfit too inconvenient and burdensome, the 4 x 5 should be a very satisfactory size. Although the 4 x 5 is not an ideal size for the purpose, it is worthy of most serious consideration as a standard size for use away from the station plats. Plainly, the present tendency is toward the use of smaller cameras equipped with the best of lenses. The smaller the camera the more essential it is that the lens be of the very best quality. For general use a high-grade anastigmat, the component parts of which may be used singly, should be selected. A speed of f/6.3 or f/6.8 will be found adequate for such work.

Since one of the greatest difficulties in field photography, especially on windy days, is that of getting sufficient sharpness, it seems advisable to discuss briefly the most important factors affecting depth of focus, which is the distance from the nearest to the farthest objects that appear sharp when the lens is focused on any given point.

First, let us consider the effect of focal length on depth of focus. Compare the depth of focus of a 4 3/8-inch lens with that of a 12-inch lens, both used at f/8 and focused on 25 feet. The first and the last figures in the fourth column of Table 1 give the desired information. Under the assumed conditions the 4 3/8-inch lens will give a depth of 66 feet minus 15 feet or 51 feet; the 12-inch lens only 27 feet minus 23 feet or 4 feet. This table shows that of two lenses with the same speed but of unequal focal length, the one of shorter focal length will have the greater depth. Clearly, then, the longer the focal length of the lens used, the more difficult it is to get sharp pictures.

TABLE 1.—*Showing the nearest and farthest objects in focus when lenses of different focal lengths are focused with stop f/8 upon points at different distances from camera* [a]

Focal length of lens	Distances focused upon at stop f/8			
	6 Ft.	12 Ft.	25 Ft.	50 Ft.
4⅜"	62"—85"	9'—17'	15'—66'	22'—Infinity
5½"	65"—79"	10'—15'	18'—41'	28'—Infinity
6⅜"	67"—78"	10½'—13¾'	19'—35'	31'—121'
7½"	68½"—76"	10¾'—13½'	20½'—32'	35'—88'
8½"	69"—75"	11'—13'	21'—30'	37½'—75'
10"	70½"—73½"	11½'—12¾'	22½'—28'	41'—65'
12"	71"—73"	11¾'—12½'	23'—27'	43'—60'

[a] Table reproduced through courtesy of the Eastman Kodak Co., Rochester, N. Y.

Another important thing revealed by this table is the fact that the nearer the point focused upon, the greater the loss of depth of focus. For illustration, compare the depth of focus of a 12-inch lens at f/8 focused on 6 feet and on 50 feet, the figures for which are given in the last line. The chart shows that when a 12-inch lens at f/8 is focused on 6 feet, the depth of focus is limited to objects between 71 and 73 inches away; that is, a distance of only 2 inches is sharp. When focused on 50 feet, the depth of focus is 60 feet minus 43 feet or 17 feet. This explains the numerous failures of those who get too close to the subject.

Whenever conditions permit, the easiest method of obtaining great depth of focus is by stopping down; that is, using a smaller lens aperture. That is, of course, common knowledge. The effect of stopping down is well shown in Fig. 16 in which the two pictures were made on the same plate with the same lens. The picture at the left was made at f/8 and the one at the right was made at f/32. In other words, the much greater depth of focus of the picture at the right was due to the use of a much smaller lens aperture. Naturally, the use of smaller apertures necessitates placing the camera on a tripod and using a time exposure. Stopping down increases the sharpness of a picture, but it has the disadvantage of compressing the planes in the view and therefore the lens should be used at the largest aperture that will give the required depth of focus.

How properly to focus a lens is a process not understood by all. One of the most important problems to solve in focusing is that of determining the best plane to focus upon. Most people say set the camera for a distance half way between the nearest and the farthest object that one desires clearly defined. This advice is given on the assumption that when stopping down the increase in depth of focus toward the camera is equal to that beyond the plane focused

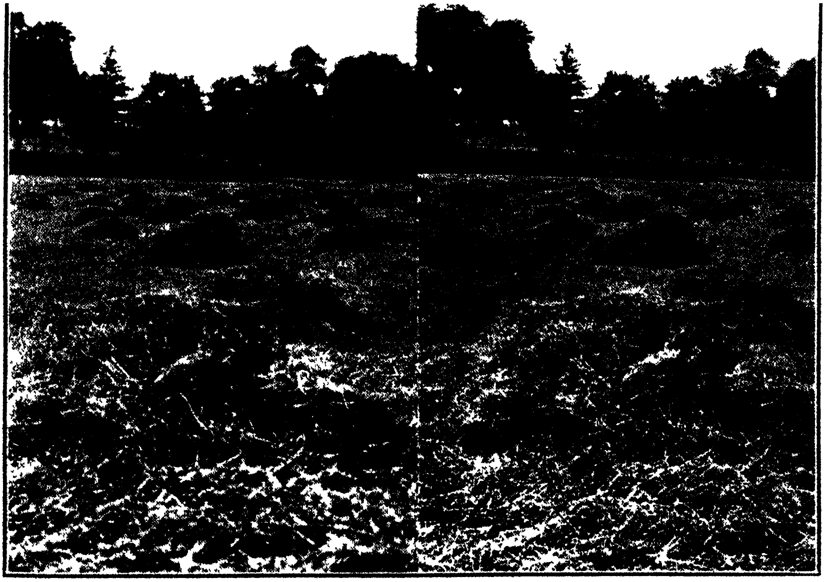

FIG. 16.—Two pictures made with a 12-inch lens showing the effect of reducing the size of the lens aperture on depth of focus. Picture to left was made at f/8; to right at f/32.

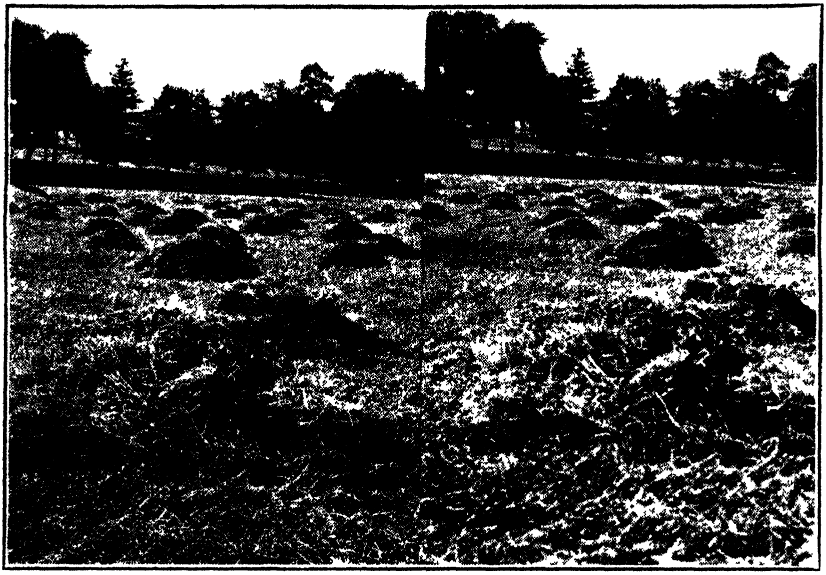

Fig. 17.—Two pictures taken to show the effect of the swing-back on depth of focus. In taking the picture to the right the back of the camera was perpendicular; in taking the one to the left the back was "swung"

upon. This assumption is incorrect. Under field conditions the depth of focus beyond the plane focused upon is appreciably greater than on the near side. Thus, it is not safe to focus on a middle distance and stop down with the expectation that the foreground will come sharp. Since the foreground is usually the most important part of the picture, the practical thing to do is to make sure that the foreground is sharp and let the distance take care of itself.

Helpful depth of focus tables are now available for those who desire to consult such aids. For those who may occasionally find use for a simple rule for calculating the best plane to focus upon the following is given: Multiply the distance of the farthest part of the subject by the distance of the nearest part; multiply this product by 2; and then divide the result by the sum of the two distances. For example, objects at 80 inches and 240 inches from the lens are required equally defined. The distance on which to focus is therefore

$$\frac{80 \times 240 \times 2}{80 \div 240} = 120 \text{ inches} = 10 \text{ feet.}$$

One of the most useful and yet least understood movements on the modern camera is the swing-back. It is a movement which can be used to great advantage as an aid in getting sharp pictures under trying conditions. Many workers consider it absolutely necessary if anything like serious work is to be done.

In a subject in which the foreground, the middle distance, and the distance are all required to be sharply defined, this means is of great assistance. Fig. 17 is an example of what can be done with a swing-back. Two exposures were made on the same plate. The picture at the right was taken with the back of the camera perpendicular; the one at the left with the aid of the swing-back. The same stop was used in each case. The photograph at the right is badly out of focus; the left, sharp. Due to the great reduction in making the cut, the difference may appear to be rather small

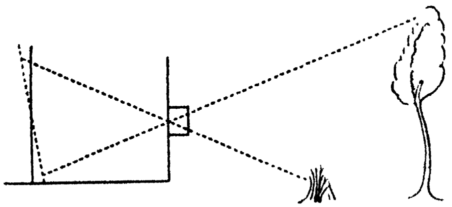

FIG. 18.—Drawing illustrating the principle of the swing-back involved in taking the pictures shown in Fig. 17.

The principle of the swing-back is easily explained. Assume that the camera is leveled and focussed on the middle distance and that the lens be used wide open. Then rays of light reflected from the foreground to the lens will focus back of and near the top of the film. Rays of light from a distant object will focus in front of the film near the lower end. It is thus evident that if the back of the camera were swung as indicated in Fig. 18 the depth of focus of the lens under these conditions would be greatly increased, permitting the use of a much larger stop and consequently shorter exposure than could possibly be used without the aid of this device. A slight amount of distortion is produced by the swing-back, but its advantages are so great when photographing under extremely difficult conditions, such as wind, that it seems that every field camera should be equipped with a highly efficient swing-back.

The visibility of objects is due to the differences in the light which they reflect. The object of photography is to translate as accurately as possible the degrees of brightness which occur in natural objects into corresponding degrees of brightness in a photographic print. If the best results are to be obtained the contrasts of the subject must be within the range of the film or plate and the direction and the quality of the light must be such as to bring out the greatest amount of detail in the subject. Anyone who has observed trees and buildings from different positions under the varying light of a

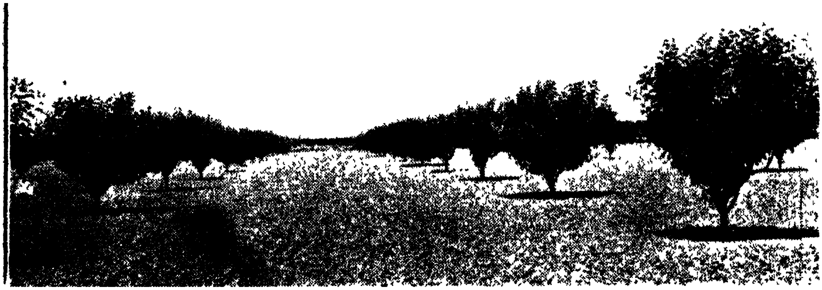

FIG. 19.—Photographs taken with the sun directly at the back of the camera or in the zenith are usually lacking in contrast and interest.

typical day can at once appreciate the fact that objects and detail do not stand out unless the light falls upon the object in such a way as to reflect both shadows and high lights.

The first thing that the ambitious beginner should forget about lighting is the old, worn-out rule that the photograph should be taken with the sun directly at the back. Such lighting usually produces a flat, and rather detailless picture (Fig. 19). In the majority of cases we find the effect of side lighting much more satisfactory (Fig. 20). It gives the greatest degree of contrast and relief. Each plane seems to stand out in front of the plane behind it, and the nearer objects have a roundness and modeling not present when

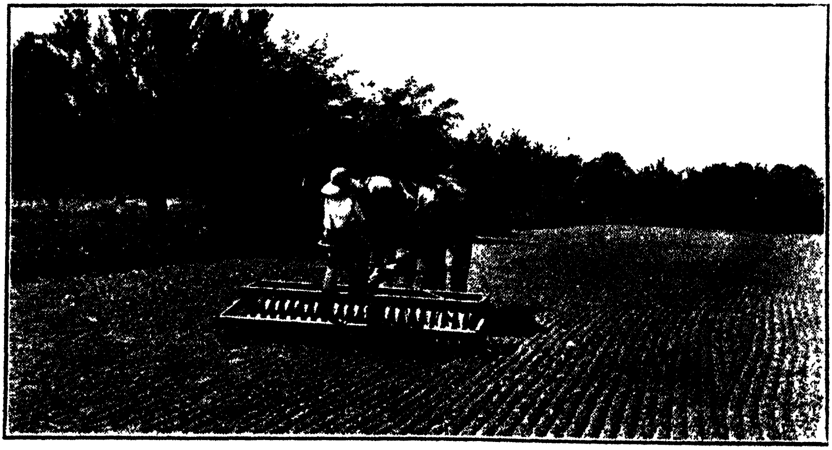

FIG. 20.—Side lighting increases contrast, detail, and interest. Therefore, the best results are usually obtained when the sun is at either side of the camera.

the lighting is from behind. As to the best quality of light for photographic purposes, we can take a lesson from the professional portrait photographer. When he wants the finest texture and quality in face, hair, delicate laces, and dress he uses soft diffused light. This should be kept in mind when working for very fine detail in delicate-toned plants. This means that as a general rule the best results in outdoor work are obtained before 10 a. m. and after 2 p. m.

The most common and disastrous error made by the average user of a camera is that of underexposure which is always indicated by a lack of detail. One should always keep in mind that the principal function of exposure is to render detail. In practical photography one exposes to get shadow detail and trusts to the latitude of the emulsion being sufficient to render the whole scale of gradation of the subject. The determination of the correct exposure can best be arrived at by the use of a reliable calculator or meter. Every amateur is strongly urged to avail himself of such valuable aids.

Many an exposure is ruined by improper development. It matters not which of the standard methods of development is used so long as it is properly carried out. Generally, it is best to use the developing formula recommended by the maker of the emulsion. The important and difficult thing about development is to know just when to remove the film or plate from the developer. Remember that exposure controls the detail; development the contrasts. Therefore, we should consider the contrasts of the subject which we are photographing and in the case of flat subjects to keep our exposures short and our development full, while in the case of strong contrasts we must give plenty of exposure and not develop too long. Tank development is a most convenient and reliable method of development, but attention should be called to the fact that trouble is likely to ensue when using some developers like pyro, for instance, if the solution is not agitated more or less during development.

6. THE POPULAR PRESENTATION OF THE RESULTS OF AGRONOMIC RESEARCH[1]

J. F. Cox[2]

Previous to the passage of the Smith-Lever Act of 1914, establishing the county agricultural agent and inaugurating the present extension system, a strong proponent[3] of this measure made the widely quoted observation that "the agricultural colleges and experiment stations had a sufficiency of facts and information concerning agriculture, held in cold storage, to revolutionize American farming methods if put into general use."

Colleges were pictured as repositories of knowledge rather than flowing wells of information, and agricultural experiment stations as cold institutions where strange individuals did unusual things which they termed agricultural research, far removed from general farm practice and of doubtful practical value in the minds of uninformed farmers.

In 1911, in a lecture to the class in agronomy at the Ohio State University, Director C. E. Thorne presented from his long experience the thought that it takes about a generation to bring a new crop or new agricultural practice into common usage.

Fifteen years has brought about a vast change in the rapidity and effectiveness of the popular reception of the results of agronomic research. Agricultural colleges and experiment stations were really as warmly interested in the farmer then as at the present time, and research workers as earnest and efficient, but the facilities for presenting new facts to the farmer were vastly inadequate as compared to agronomic extension methods of the present day. As recently as 15 years ago, the horse and buggy were the common means of conveyance, bad roads were frequent in rural districts, farmers' cooperative organizations were just beginning to develop, and county agents were few in number. While newspapers were available, trained agricultural publicity directors who could aid in presenting scientific facts to the press in a popular way were hardly known. The home use of the radio was undreamed of and moving pictures were still in the "custard-pie throwing" stage.

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[1] Paper read as a part of the symposium on "Publication of the Results of Agronomic Research" at the meeting of the Society held in Washington, D. C., November 18, 1926.

[2] Head of the Department of Farm Crops, Michigan State College, East Lansing, Mich.

[3] The late B. F. Harris of Champaign, Illinois, Chairman of the American Banker's Association Committee on Agriculture.

Today, automobiles and good roads have immeasurably reduced the degree of physical isolation which existed in rural districts, and with numerous modern publications, community meetings, moving pictures, and the radio there need be no mental isolation.

The human element plays a large part in modern agronomic extension. The great majority of farmers, because of frequent and direct contacts, actually feel that the agricultural colleges and experiment stations are theirs and are working in their interests. The idea that the agricultural college campus extends from College Halls to the borders of the state, first expressed by Dean Russell of Wisconsin, is now the prevailing idea in all states. The importance of efficient and profitable methods of crop production and of agronomic research directed toward greater efficiency in contributing toward rural home and community betterment is being realized more than ever before by leaders in the Country Life Movement.

In presenting the results of his work, the agronomic research worker is on safe grounds in preparing a paper for the American Society of Agronomy, or for other scientific journals or experiment station technical bulletins. Such treatises are not, however, widely read by the public. Important as these vehicles may be for the first announcement of research results, it is necessary that other means of thought transference be used in reaching a large number of those engaged in crop production, for whom the results secured are of particular value.

It behooves the research worker to keep in mind that the measure of effectiveness of the results of most research projects, and their value to the state or nation, are determined by the extent to which the new method, new variety, or new fact is employed in the practical field. He should, therefore, continue his interest in research projects which have borne fruit to the point where the general public has been properly reached. Fortunately, the research worker is substantially aided in making his work effective in the field of farm practice by extension specialists and teachers in agronomy, trained agricultural journalists, county agricultural agents, and informed farm leaders.

In reaching the agricultural public by use of the printed word, it is doubtful if any agencies are as effective as the farm journals, the weekly and daily newspapers, and farm organization papers. Well-prepared experiment station and extension bulletins still have their place, and both experiment station and extension publications at monthly and quarterly intervals reach wide fields, but established newspapers and farm journals are apparently more widely read.

A good farm journal has an intimate place in the farm family reading circle and the timely and interesting presentation of the results of important agronomic research in such a journal insures that it will be read attentively by a great number of interested readers.

The weekly newspapers, carrying as they do local items of news and printed by an editor often personally known by the reader, are read by farmers with a peculiar interest.

A government or experiment station bulletin reporting the results of agronomic research, may be set aside at the end of a hard day for future reading, but a properly prepared news article in the local paper, giving the salient facts of such research in such a way as to meet the approval of the news sense of the local editor, will be read with much the same interest as the local news.

County agents and crop and soil specialists who work with county agents have become the most forceful allies of the research worker in getting the results of his work to the public. The crops and soils program of the modern county agent is planned to bring into common use in the county the best practices and varieties contributed by research. Under special conditions, the ordinary progress of the county agent's program may be expedited by the campaign method.

Special alfalfa meetings, or alfalfa-dairy campaigns held in the field or in the barn, in Michigan counties remarkably expedited the increase of alfalfa acreage. Ten days or two weeks spent in a county, with two teams on the job holding four or five meetings per day, can be counted on to reach from 1,200 to 2,400 farmers per county in a most intimate and direct way.

The corn borer, a special emergency, is being met in a similar manner. Over 1,000 Ohio farmers have been taken on field tours to damaged Canadian fields, and a large number from Michigan counties. This year, however, sufficient injury was done in one 6-acre corn field in Michigan so that it was unnecessary to go to Canada to see total loss from the corn borer.

In these days of easy transportation, visitations to experiment stations or to field demonstrations are usually arranged with comparative ease. Farmers' weeks and summer experiment station field days are attended by large crowds and an excellent opportunity is offered to study the actual results of agronomic research under way and to prepare special demonstrations. Substations and demonstration farms have become immensely important in the areas which they serve. County cooperative demonstration tests of crop varieties, of alfalfa and clover seed from various sections, of planting, cultural, and harvesting methods, etc., serve as a basis for excellent field meetings arranged in cooperation with the county agent.

Alfalfa hay days arranged by extension specialists and county agents for the purposes of showing the best methods of curing alfalfa hay are drawing large crowds of interested farmers in many counties.

Special agronomic exhibits prepared for farmers' week programs, state and county fairs, and national exhibitions must be graphic and easily understood. A "chart show" is about as interesting to a farmer or his boy at the fair as the family washing hung out on the line. On the other hand, good specimens of crops or excellent seed, photographic enlargements of fields and field operations, concise and graphic demonstrations by approachable demonstrators of soil and seed testing, new machinery, etc., and moving pictures will receive attention.

The Smith-Hughes agricultural teacher has appeared in recent years as one of the most important factors in carrying practical results of agronomic research to farm communities. These teachers are college trained and maintain by special short courses and round-up-meetings close contact with their state agricultural colleges. Most of them conduct demonstrations of new varieties and improved cultural methods in cooperation with their students. The agronomy department which does not cooperate with Smith-Hughes teachers, providing a specially trained contact man to aid in planning agronomic demonstrations with Smith-Hughes teachers, conducting judging contests and suggesting displays, is missing a great opportunity for carrying modern agronomic research work to a new and important field.

The radio has come as the latest means of reaching a large public. The research worker himself or the teacher or extension specialist in agronomy can be assured of a wide hearing. Farmers who have utilized the results of agronomic research on their farms make excellent additions to radio programs. Agronomic talks over the radio which fit seasonal conditions or emergencies are unusually effective. There is no way of actually measuring the number of hearers, but the influence of the radio is greater than the average conception, as the following instance indicates.

The 1926 fall season was unusually wet and beans were being harvested with difficulty in Michigan. In order to help meet the situation, H. R. Pettigrove, Bean Specialist at the Michigan Station, announced over the radio the results of his investigations of a method of curing beans by stacking around steel fence posts or poles, using ten to the acre and stacking the beans on a pad of straw about 5 feet in diameter and 1 foot thick. Within a few days, this method was in use by many farmers widely scattered over the Michigan bean-growing area.

As an example of the rapid effectiveness of the presentation of modern research, none is more outstanding than the changed situation in regard to the commercial distribution and use of alfalfa and clover seed.

Scientific research on the part of federal and state workers disclosed the fact that adaptation was of paramount importance in determining crop yields of clover and alfalfa. Investigation of trade movements of seed showed that great losses were being brought about through the distribution of Argentinean and African alfalfa seed and Italian red clover seed in northern and corn belt states. These facts were published through all the agencies previously mentioned. Alfalfa and sweet clover seed growers formed seed certifying agencies. The cooperative distribution of adapted seed followed in many states. The Federated seed service functioned strongly in working with the American Farm Bureau Federation in forwarding the production and use of seed of known origin and in forwarding legislation. Michigan placed a clause in her seed law requiring that the state, territory, or foreign nation be stated (along with analyses and germination test at a certain date) on all seed of clover, alfalfa, corn, and soybeans offered for sale.

The American Farm Bureau espoused the passage of the Gooding-Ketcham bill which requires the staining of imported red clover and alfalfa seed in such a manner that its source can be distinguished. This bill also requires that generally unadapted and hence undesirable imported clover and alfalfa seed be stained red to the extent of 10%.

Farm organizations, such as the Farm Bureau, cooperative associations, and the Grange, have brought new forces to bear in carrying the results of valuable research to the farmer. The modern department of agronomy must prepare the right kind of material for the publications of these organizations, and when invited to provide a speaker for the annual meetings or special meetings of such groups should fully appreciate the opportunity offered to present recent research results of value to these audiences.

Crop improvement associations, experiment associations, certified seed potato growers associations, soil improvement associations, and other cooperative associations have become major extension forces in most states. They not only make immediate use of new varieties and new methods, but are practical and efficient agencies in making new developments felt in a state-wide way. The plant breeder working in a state without a well-organized crop improvement association is working under a terrific disadvantage in securing widespread increase of improved varieties. Fortunately, in nearly all states maintaining plant breeding work, a more or less well organized crop improvement association is to be found.

The agronomic research worker today has the inspiration and satisfaction of seeing a new practice or an improved variety brought into widespread use with amazing rapidity through the employment of the varied and effective means of modern extension methods.

A dollar spent in agronomic research today gives more immediate and greater returns to the public than the research dollar of any other period.

The responsibility of the research worker, however, was never so great as in this day of rapid and effective contacts with the farmer. He must be exceedingly sure of his results and their effect on farm practice before the efficient machinery of modern extension carries them to the far corners.

THE PREPARATION OF MANUSCRIPT FOR THE JOURNAL OF THE AMERICAN SOCIETY OF AGRONOMY

(Suggestions by the Editors)

In editing copy submitted for publication in the JOURNAL of the American Society of Agronomy every effort is made to preserve, so far as possible, the individuality of the author's style. It seems desirable, however, that a certain degree of uniformity in the general arrangement of material published in the JOURNAL should be maintained, and the following suggestions are offered as an aid to those who prepare manuscripts for publication in this JOURNAL.

GENERAL STYLE

Prospective authors are requested to study recent issues of the JOURNAL as examples of the general style of writing which is maintained as a standard and, so far as possible, to conform to that standard in the preparation of their articles.

Clear, concise, correct statements are desired, rather than long, involved sentences. Above all, an account of an investigation should be written in the third person. The use of first or second person pronouns in the JOURNAL is permitted only when the personal views of the author or reader are the point at issue rather than the facts in the case.

The title of the article should be as brief as possible, although at the same time it should convey an accurate impression of the contents of the paper.

HEADINGS

The logical presentation of the results of an investigation presupposes a definite outline prepared in advance. This outline should comprise a few main headings sufficiently subdivided to indicate clearly the relationship of the various parts of the discussion to the whole. These headings should appear in the manuscript as prepared by the author.

For most purposes it will be unnecessary to provide headings of more than three grades, *viz.*, main headings, secondary headings, and side headings. Excessive refinement in subdividing the text should be avoided. The main headings and secondary headings stand in the center of the page and are set in different size type to show their relative importance. Side headings are printed in italics, and almost invariably indicate subdivisions under the secondary headings. Only a small amount of text matter; preferably not more than a page, should be covered by a side heading.

Each heading should contain a substantive and should indicate the thing or things described or discussed in the text.

TABLES

All tabular matter should receive close study in order that it may be presented in the clearest possible manner. Arabic numerals are used in numbering tables in the JOURNAL. Also, tabular matter is always set without rules, necessitating close attention to column headings if the tables are to be readily understood.

Brief, explanatory legends are preferred, but the legend should be complete in itself so that the table can stand without reference to the text.

An example of a good heading is as follows:

TABLE 2.—*Effect upon yield of potatoes of spraying with paris green.*

The following is not a satisfactory heading:

TABLE 2.—*Results of first experiment.*

Units of measure are ordinarily written out in full over the columns to which they refer.

Where decimals occur in tabulated data, and elsewhere in the article, ciphers should be used wherever significant figures are lacking, otherwise omit the decimal point, as 29.25, 32.00, etc. Also, the decimal point should be preceded either by a significant figure or by a cipher, as for example 1.25 or 0.25; not .25.

Footnote references in tables should be indicated by means of superior italic letters.

The following example is offered as a desirable form for presenting tabular matter in the Journal.

Table 2.—*Effect upon yield of potatoes of spraying with paris green.*

Plat No.	Yield per plat		Yield per acre	
	Total Yield *Pounds*	Marketable tubers[a] *Pounds*	Total yield *Bushels*	Marketable tubers[a] *Bushels*
1.	15.75	12.85	149	125
2	14.50	12.00	146	119
3	14.90	12.50	147	123

[a] Tubers over 2 ounces in weight.

QUOTATIONS AND REFERENCES

It is taken for granted in editing manuscript for the Journal that the author assumes responsibility for the accuracy of quotations and literature citations, although occasionally these are verified where discrepancies are suspected.

In quotations the exact words of the original should be preserved. It is not essential in such cases, however, to reproduce typographic errors, or details of style, such as spelling, capitalization, or punctuation, which are at variance with the form approved by this Journal, unless these differences are to be preserved for some particular purpose.

Literature citations if more than three should be grouped at the end of the article under the heading of "Literature Cited." Three citations or less should be given in footnotes.

Reference in the text to literature citations should be indicated by figures in parenthesis, for example, Brunson (1). The form of citation used in the Journal is as follows.

1. Brunson, A. M. The relation of inheritance studies to corn improvement. Jour. Amer. Soc. Agron., 18:308–314. 1926.

In citations of experiment station publications the state names are abbreviated, as is also the United States Department of Agriculture, thus, N. Y. State Agr. Exp. Sta. Bul. 530; U. S. D. A. Bul. 1120.

CAPITALS

The word "state" should not be capitalized unless used with the state name, such as New York State. The word "county" should be capitalized if used before or after the name of the county, such as Ontario County. Terms applied to groups of states, as North Atlantic, South Atlantic, etc., should be capitalized, also terms denoting sections of the United States, as the West, the South, etc., but use eastern Gulf States, western New York, etc.

The terms "corn belt," "cotton belt," etc., should not be capitalized.

The words "experiment station" or "agricultural experiment station" should be capitalized only when used with the name of the institution, such as the Illinois Experiment Station.

The names of genera, families, orders, etc., should be capitalized, but names of species should be written with lower case.

Words that have come into such common use that all thought of their origin has disappeared, such as paris green, bordeaux mixture, etc., should be written with lower case letters.

Also, use a. m. and p. m.

ORTHOGRAPHY

The Standard Dictionary should be used as the authority for spelling, compound words, etc., except where in conflict with recognized usage in the case of scientific terminology as indicated by leading scientific journals.

The forms "sulfur," "sulfate," and "sulfuric" are used in the JOURNAL, as is also "plat" rather than "plot." In expressing percentage the % sign is used.

NUMERALS

All amounts of ten or less should be spelled out, *except* enumerations of weight, measure, distance, clock time, money, percentage, degrees, proportion, and age, when figures should be used. Figures should also be used in groups of enumerations where any one enumeration is in excess of ten. Also, treat alike all numbers in connected groups.

To avoid confusion where two numbers occur together, as "11 2-ounce tubers," write "eleven 2-ounce tubers."

Figures beginning a sentence should be spelled out, also both numbers of two related amounts at the beginning of a sentence, thus, "Ten to twelve kernels were selected."

Numbers of 1,000 or more should be written with the comma, except of course in the case of year numbers.

Use figures for decimal fractions and supply a cipher when there is no unit, as 0.25. Avoid a mixture of common and decimal fractions. Common fractions standing alone should be spelled out, as "one-half inch," but write "3½." Use the expression "one-fourth" rather than a "quarter."

Dimensions should be expressed as "8 by 12 inches," not "8 x 12 inches". Also in expressing range use "10 to 20 inches," not "10–20 inches."

Where dates occur in the text the name of the month should be written out in full and the day without termination, as "January 15," not "Jan. 15th."

ABBREVIATIONS

Units of measure, such as grams, pounds, bushels, inches, gallons, etc., should be written in full in the text, and, so far as possible, when used at the head of a column in a table.

However, when necessary, use cm. for centimeter, cc. for cubic centimeter, mm. for millimeter, cmm. for cubic millimeter, mg. for milligram, kg. for kilogram, sp. gr. for specific gravity, p. p. m. for parts per million, F for Fahrenheit, and C for Centigrade.

In expressing hydrogen-ion concentrations use the form pH.

READING PROOF

Galley proofs of all articles published in the JOURNAL are sent to the authors, together with the manuscript, in ample time for a careful reading of the article in type before publication. Prompt attention to the reading of the proof and its return at the author's earliest convenience will be appreciated by the Editors, as the JOURNAL cannot go to press until all proof has been returned.

In all cases the manuscript should be returned with the corrected proof.

Corrections on the galley proofs should be limited to only the most essential changes. The Editors exercise every care in the correction of typographical errors, but cannot assume responsibility for errors in statement of fact or in tabular matter that may have crept into the manuscript. Therefore, a careful reading by the author back to the original copy is highly desirable.

BOOK REVIEWS

A PRELIMINARY REPORT OF AN INVESTIGATION INTO THE ARTIFICIAL DRYING OF CROPS IN THE STACK

Bulletin No. 2. Institute of Agricultural Engineering, University of Oxford, Oxford University Press, American Branch, New York. 104 pp. 8 plates. $0.85. 1926.

This report is published only in pamphlet form, with paper covers, but the material presented is of such unusual and special interest to agronomists that notice of it under the general heading "Book Reviews" seems justified.

Part I of the report presents the results of field experiments conducted at several places in England and Ireland in 1923, 1924, and

1925. The first year's attempts at artificial drying of peas, barley, meadow hay, and alfalfa were generally unsuccessful, but pointed the way to improvements in the method used. The trials during 1924 of drying hay, oats, and clover in stacks with heated air demonstrated the practicability of the method and indicated the necessary types of equipment. During 1925, eighteen successful demonstrations of the process of artificial drying of stacks of mixed grasses, etc., were conducted in Ireland; and experiments to ascertain the best arrangement of material and equipment and the cost of operation were carried on at Oxford. These experiments and demonstrations are described in detail in the bulletin.

The final results showed that the average time required for complete drying of 18 stacks (average size, 12 tons of finished material) of green oats and mixed hays, during a persistent spell of rainy weather, was 11 hours and 20 minutes; thus demonstrating that it is possible to dry during the night a stack of green material put up during the preceding day, even under unfavorable weather conditions. The cost of operation, at English rates for labor and fuel, averaged about $1.25 per ton.

Part II deals with "Laboratory Work and Theoretical Considerations" and presents in full and careful details the various chemical and engineering aspects of the method: Such as, charts and tables of velocities of air movement; temperatures required for evaporation of moisture; effect of size and shape of stack on rate of evaporation; analyses of resultant hays; etc.

Several appendices include separate papers presenting various aspects of the general investigations. Appendix III, "The Crop Drying Plant," gives a complete and concise description of the method of operation. The plates give excellent views of the various types of heaters which were used in the experiments and demonstrations. (R. W. T.)

THE PRINCIPLES AND PRACTICE OF YIELD TRIALS

By F. L. Engledow and G. Udny Yule. Pub. by The Empire Cotton Growing Corporation, Millbank House, Millbank, London, S. W. 1. 78 pp. 1926.

This pamphlet, which is available for free distribution from the offices of the publishers, is an unusually careful discussion of field technic and mathematical treatment of the results of yield trials with farm crops, with no special reference to cotton or any particular crop.

Section I discusses "The Difficulties of Yield Trials and the General Principles," and Section II presents "Practical Considerations and Procedure."

The authors are well-known members of the faculty of the School of Agriculture at Cambridge and their treatment of the subject is characteristically careful and sound. (R. W. T.)

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THE FARM CROPS LABORATORY[1]

F. D. KEIM[2]

It is the purpose of this paper to show in detail some of the equipment and practices that have tended to raise the efficiency of the laboratory teaching of farm crops at the University of Nebraska. It is not the purpose of the writer to give the impression that the ideas set forth in this paper are perfect and that this is the only way to handle these situations. It is believed, however, that some of these points will be of interest to others in the field and that this paper may stimulate the publishing of new and old ideas that would be of value to teachers of farm crops.

The general location, the size, the equipment, and the proper organization of the laboratory are some of the most important factors in the successful handling of students in any laboratory. Since there is so much bulky material used and since crops bundle material is almost sure to shatter and litter up the stairs and halls of a building, it is better to have a crops laboratory on one of the lower floors. If it is necessary to have a laboratory on the second or third floor, or if the laboratory is on a different floor than the storeroom, an elevator is always a valuable asset.

The dissection of grass and legume flowers and the study of small seeds are usually a part of the laboratory procedure. It is therefore necessary that this room have the very best light available. A corner room is usually to be preferred since light comes in from two sides. Large, unobstructed windows, and as many of them as possible, will aid materially in holding the interest of students. A south room is usually to be preferred over a north room because on dark, cloudy days a north room becomes so dark that study and close examination of plants and seeds is very difficult. In addition to the natural light the best kind of artificial light should be provided. There are always dark days in winter when artificial light must be used. One or two large lights near the ceiling in the center of a large room are never satisfactory. If the lights are well distributed and are hung on cords 3 or 4 feet from the ceiling, a very good lighting effect can be provided.

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[1] Published with approval of the Director as Paper No. 27, Journal Series, Nebraska Agricultural Experiment Station. Received for publication October 27, 1926.

[2] Professor of Agronomy, University of Nebraska, Lincoln, Nebr.

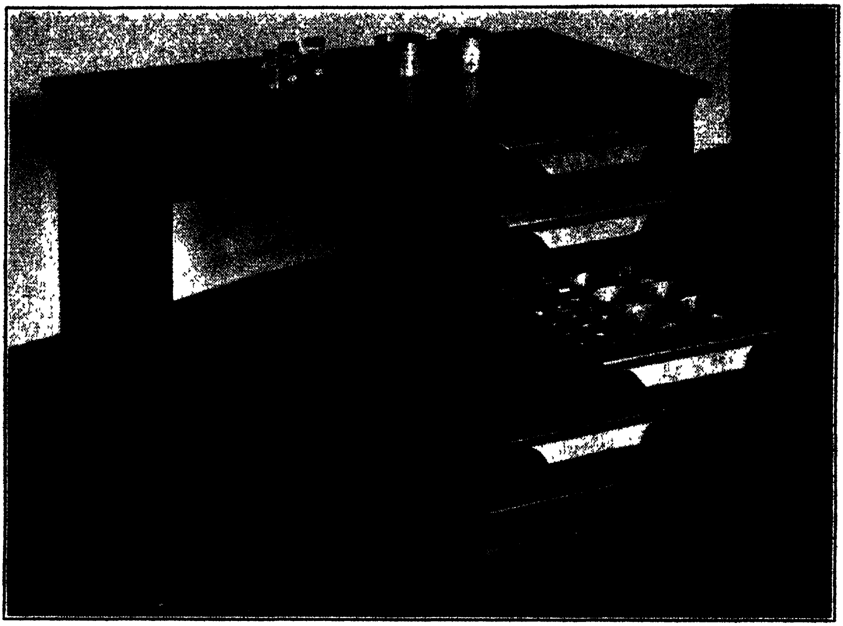

FIG. 1.—An individual crops laboratory desk that has been in constant use for 18 years. Notice the legend on the cans showing desk letter, drawer number, and can number.

Sunlight blinds adjustable at both bottom and top are much better than the old ordinary colored window blinds.

There has been much discussion concerning the size of room and the number of students that one teacher can handle in any given section. The writer prefers a rather large room, at least 30 by 50 feet. In a room of this size, 36 individual laboratory desks can be placed and still have plenty of room for aisles. Where an instructor has had several years' experience and where well-prepared laboratory outlines are available, 25 or 30 students make a very satisfactory division. There probably will be certain exercises that will require more help and an assistant would prove valuable during these periods.

The writer prefers individual desks over long tables for a general farm crops laboratory. Fig. 1 shows the type of desk used in the farm crops laboratory at the Nebraska Agricultural College. These desks are very satisfactory with one exception. In the place of the lower drawer the desk should be equipped with short legs so that all waste grain can be removed after each day's work. In other words the desk should have a sanitary base. To be sure, these desks can be easily moved, but unless dirt can be seen, it is not likely that the desk will be moved and the grain and trash swept from under it. Any loose grain lying under the desks or any other waste place is almost sure to be a fine breeding ground for the Angoumois grain moth and grain weevil.

Desk tops should be made of hard wood. Students are not so likely to follow a groove made by a pencil mark and use a knife on hard wood as on soft. The desk shown in Fig. 1 has been in use for about 18 years and is still in good condition. If a small block of wood (2 by 3 inches) can be provided on which to cut kernels of grain and for other operations where a knife is used, it will save the desk many useless scars. Little scars soon grow into big ones.

The top surface of these desks is 25 by 40 inches. There are times when desks somewhat larger would be better, but if they are much larger they fill up a room so quickly that too few students can be accommodated. Each of these desks contains five drawers. Fig. 2 shows a detailed drawing of each of the first three drawers and their compartments with the size of the drawer and the width of the divisions. The divisions within the drawer are made of galvanized iron. The small circles represent 2-ounce petrolatum bottles with screw caps and the larger ones ordinary pint tin cups. Each of these containers are labelled with the desk letter, the drawer number in Roman numerals, and the number in Arabic numerals signifying its number in the desk.

For example, Can "10" in Drawer "3" and Desk "A" would be labelled as follows: A III 10. A system of this kind always makes it possible for each student to file the materials back in proper order when he is through with them. Grains or seeds of any kind when once taken out of a container are discarded after using. This helps to avoid mixing. Each student is assigned a desk. The number of students assigned to any particular desk depends on the number of divisions. By an arrangement of this kind, any damage done to the desk can usually be traced without much difficulty, and besides this system aids in establishing a well-organized laboratory.

The material placed in the containers, of course, depends quite largely on the locality and the course offered. The materials used in the Nebraska laboratory desks are shown in Table 1.

It is very important that the cans be emptied at least twice each year. If this is not done, the grain is almost sure to be badly infested with the Angoumois grain moth and grain weevil. There is also a

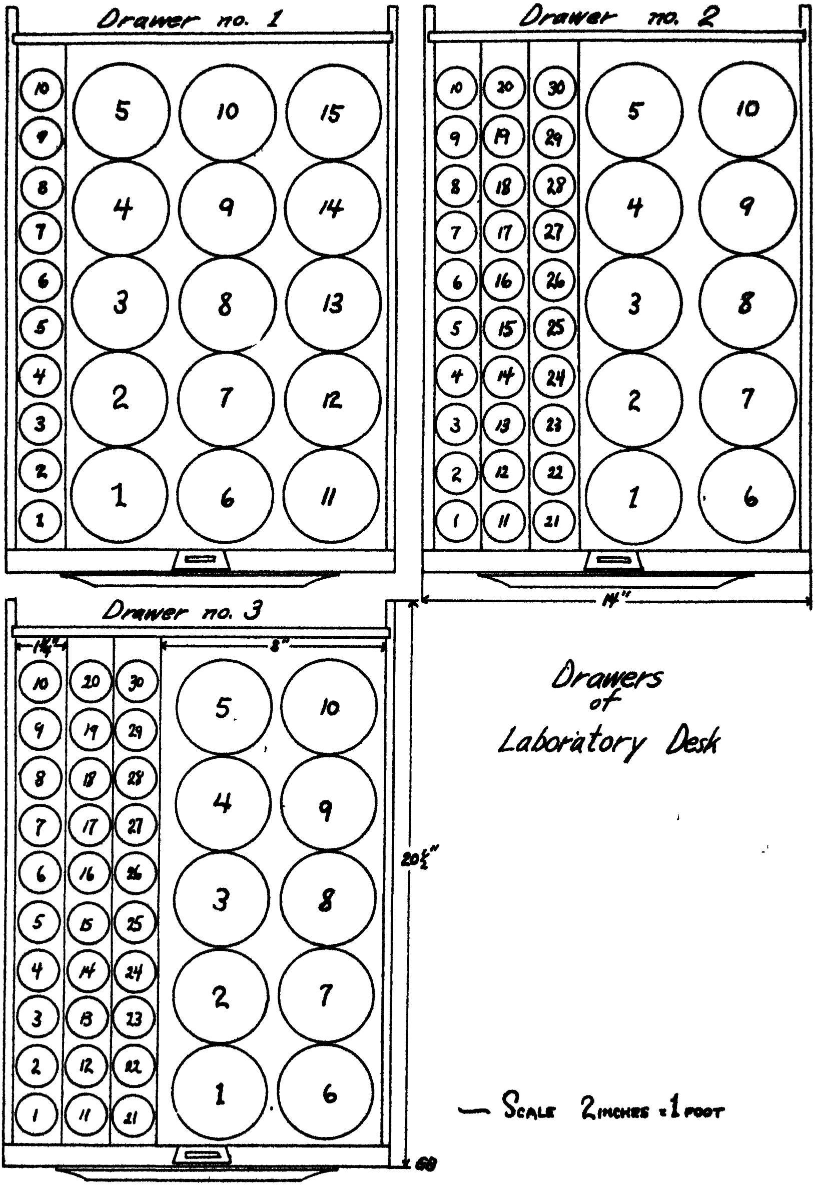

FIG. 2.—A detailed drawing of the three upper drawers in one of the laboratory desks showing the different compartments.

TABLE 1.—*The materials used in the laboratory desks.*

Two-oz. bottle No.	Drawer I
1	Einkorn
2	True beardless winter spelt
3	True bearded spring spelt
4	White spring emmer
5	Black winter emmer
6	Common Turkey Red
7	Little Club
8	Poulard
9	Durum
10	Polish

Can No.	Wheat
1	Turkey red from eastern Nebraska
2	Turkey red from western Nebraska
3	Durum from eastern Nebraska
4	Durum from western Nebraska
5	Northern spring from North Dakota (Marquis)
6	Yellow red winter from South
7	Little Club from Pacific Coast
8	Gypsy wheat from Illinois
9	Red Walla from Washington State
10	Dark hard winter, grade 1
11	Hard winter, grade 1
12	Yellow hard winter, grade 1
13	Yellow hard winter, grade 2
14	Yellow hard winter, grade 3
15	Yellow hard winter, grade 4

Two-oz. bottle No.	Drawer II
1	Swedish Select, English-grown
2	Swedish Select, Nebraska-grown
3	Black Victor, English-grown
4	Black Victor, Nebraska-grown
5	White Kherson, Nebraska 21
6	Yellow Kherson
7	Burt
8	Texas Red
9	Naked oats (*Avena nuda*)
10	Wild oats (*Avena fatua*)
11	Black amber sorghum
12	Orange sorghum
13	Sumac sorghum
14	Red kafir
15	Pink kafir
16	Black-hulled white kafir
17	New shallu
18	Brown doura
19	White doura
20	Milo
21	Feterita
22	Brown kowliang
23	Broom corn
24	Pearl millet
25	Common millet
26	German millet
27	Siberian millet
28	Hungarian millet
29	Yellow broom corn millet
30	Japanese barnyard millet

Can No.	Oats
1	Clipped oats
2	Black oats, grade 1
3	Gray oats, grade 1
4	Red oats, grade 1
5	Mixed oats, grade 1
6	White oats, grade 1
7	White oats, grade 2
8	White oats, grade 3
9	White oats, grade 4
10	White oats, sample

Two-oz. bottle No.	Drawer III
1	Timothy
2	Red top, recleaned
3	Red top, in hull
4	Kentucky blue
5	Orchard
6	Meadow fescue
7	Perennial rye
8	Brome (*B. inermis*)
9	Cheat (*B. secalimus*)
10	Tall meadow oat
11	Slender wheat
12	Johnson grass
13	Bermuda
14	White clover
15	Alsike clover
16	Red clover
17	Crimson
18	Burr clover
19	Yellow trefoil
20	Common alfalfa
21	Turkestan alfalfa
22	Small yellow annual sweet clover
23	White sweet clover, biennial
24	Sweet clover in hull
25	Rye
26	Rice
27	Buckwheat (Japanese)
28	Cotton
29	Soybeans
30	Cowpeas

Can No.	Barley
1	Six-row white covered (Oderbrucker)
2	Six-row white naked
3	Six-row black naked
4	Two-row white covered
5	Two-row black covered
6	Two-row white naked
7	Six-row white covered, grade 1
8	Six-row white covered, grade 2
9	Six-row white covered, grade 3
10	Six-row white covered, grade 4

chance that the grain will become mixed so badly that identification studies from these cans may be very misleading.

Of course, there is a great deal of material that is used in the laboratory that cannot be placed in the desks. All material for studies of inflorescence and for vegetative study must be handed out each day. But to have on hand many of the stable supplies in such convenient form that a student can reach them in a moment will assist greatly in saving the students' and teacher's time.

The two lower drawers of each desk are used for a number of purposes. When corn types and corn adaptation are being studied, the samples illustrating these points are temporarily stored here. When studying the inflorescence of the small grains or the grasses each student is required to take a clean sheet of note-book paper and fasten to the paper a spike or panicle of each type. He does this by punching two small holes in the paper and then runs the culm through. These are all properly labeled and are stored in the lower drawers of the desk for future reference. Only those common types and varieties that the student may be expected to know by sight are handled in this way.

The whole plant of the various varieties and subvarieties of the grains and the small-seeded grasses are handed out as they are used and classified with the various keys now available. Clark, Martin, and Ball's (2)[3] classification of American wheat varieties, Etheridge's (3) classification of the varieties of cultivated oats, Wiggans' (7) classification of the varieties of cultivated barley, Mosher's (5) grasses of Illinois, Wilcox, Link, and Pool's (6) handbook of Nebraska grasses, Carrier's (1) identification of grasses by their vegetative characters, and a number of other guides may be used for this purpose.

Another feature that has proved of value is a note-book rack. Fig. 3 shows a picture of this rack with one door open. The student can always get permission to take his note-book out for study, but ordinarily the note-book, together with his laboratory manual, is filed in the cabinet. This is a convenience to the student and the notes are usually on hand for the teacher to examine. The student is assigned a number corresponding to the number on the file and all papers are corrected and placed in this note-book file. This saves valuable time for the class period.

One of the most valuable assets in connection with the general crops laboratory and also the grain grading laboratory is the fumigation room (4) which is located directly across the hall on the same floor. Here the bulk materials can be kept free from moths and mice. Even with this room so near, it is convenient to have most of the grading and judging samples in the laboratory. To meet this need a case with 30 drawers which contains classes of judging corn ready for use is located in the back part of the room. Another case is provided with drawers which hold about 1 peck and contain several judging classes of each of wheat, oats, and barley. These cases are made so that the grain can be fumigated with carbon bisulfide without removing the drawers. It is necessary to change these samples rather frequently but this can be done at odd times by advanced students with the instructor's help.

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[3] Reference by number is to "Literature Cited," p. 80.

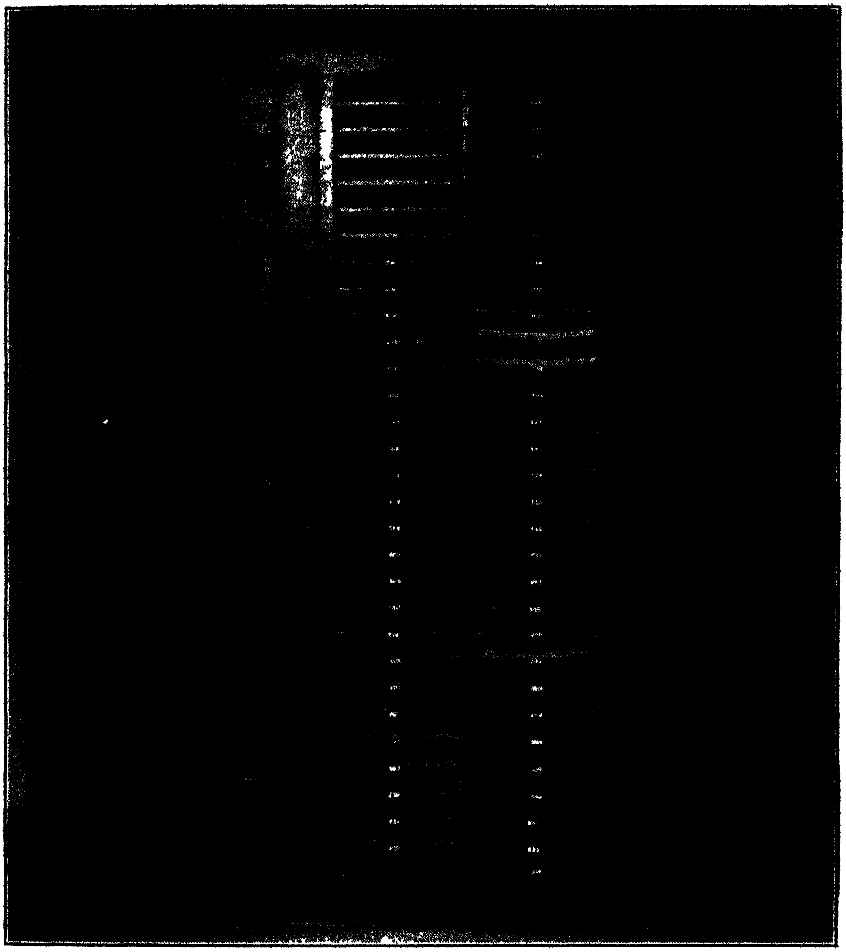

Fig. 3.—A laboratory note-book and quiz paper filing case. This case contains 120 compartments, each compartment being 12 by 10 by 2 inches, inside measurements.

Most of this paper describes inside laboratory equipment. The writer feels that this is important but believes that the best teaching is done in the big out-of-doors laboratory. As much field work as possible should be combined with the laboratory procedure, but in the latter proper equipment and organization is essential if the work of the laboratory period is to be successful.

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THE CRITICAL PERIOD OF APPLYING IRRIGATION WATER TO WHEAT[1]

A. KEZER and D. W. ROBERTSON[2]

INTRODUCTION

The effective use of irrigation water is one of the vital problems which confronts the farmer and the scientist in irrigated sections. A knowledge of the effect of the application of water at different growth periods on yield and quality of the grain may assist materially in obtaining an economical use of irrigation water. As the area of irrigated land increases, the amount of available water per acre of irrigated land decreases. Under such a condition a knowledge of the time to apply a limited amount of water to obtain maximum results is of importance. A study of this problem made under controlled conditions is reported in this paper.

REVIEW OF LITERATURE

Von Seelhorst (14)[3] worked in Germany with wheat grown in pots containing soils of different moisture content. He concluded from his work that a high moisture content at the shooting stage increases the yield and quality of the grain.

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[1] Contribution from the Department of Agronomy, Colorado Agricultural Experiment Station, Ft. Collins, Colo. Received for publication November 1, 1926.

[2] Chief Agronomist and Associate Agronomist, respectively.

[3] Reference by number is to "Literature Cited," p. 115.

Von Seelhorst and Kryzmowsky (15) report the results of experiments with oats in which the soil was kept at a low moisture content at the early part of the season and at a high moisture content at the later end of the growing season. The soils were kept moist from the following dates: May 1, May 15, June 1, June 15, and July 1 to the end of the growing season. In another set of experiments the soils were kept moist up to these dates and dry afterwards. In the first set the yield was highest in the pots kept moist from May 1 on and decreased with each 15-day difference to July 1. In the second set the yield was highest where the soil was kept moist until July 1 and decreased as the moisture period shortened.

Harris (6) reports the following results from experiments conducted at the Greenville Farm, Utah. Wheat was grown under field conditions (average precipitation of 16.5 inches) and single irrigations of 5 inches of water were applied to plats at the following stages in the growth of the plant: (a) Check, no water applied; (b) when five leaves had developed and the plants were 6 or 8 inches high; (c) the early boot stage when the plants were just swelling preparatory to heading; (d) the bloom stage when most of the plants were in bloom; and (e) when the plants were in the dough stage. The following conclusions were drawn: The heaviest kernels were produced on the plats receiving 5 inches each at the fourth and fifth stage, while the lightest kernels were produced on the plats receiving a 5-inch irrigation after the grains were planted and before they came up. The heaviest weight per bushel was obtained when a 5-inch irrigation was applied at the fifth stage. The number of kernels per head was the highest in the plat receiving a 5-inch irrigation before the plants came up.

With barley Harris and Pittman (8) obtained the highest yield of grain with a 5-inch irrigation applied at the second (early boot) stage and the highest yield of straw when a 5-inch irrigation was applied at the dough stage. When water was applied at the bloom stage the grain weight was increased to a greater extent than when water was applied at the five-leaf stage.

With oats these workers (7) found that 5 inches of water applied after the grain was planted and before it was up decreased the yield. The heaviest grain and straw yield was obtained when 5 inches of water were applied at the five-leaf stage. The best quality of oats was obtained when water was applied at the early boot stage.

Etcheverry (4) sums up the work of several stations as follows, "Investigations carried on in California, Idaho, Montana, and Utah indicate that the yield of crops does not depend entirely on the quantity of water, but on the time when it is applied. It has been found that, when water is properly applied so as to eliminate controllable losses, different quantities of water will give different crop yields, but that the increase in yield is not in direct proportion to the increase in quantity of water applied and for some crops at least there is a total depth of water which will give a maximum yield and any quantity in excess of this is not only wasted but decreases the yield, the plants suffering because of excess moisture." Also, that "The temperature of the water may have considerable effect on the proper time of beginning of the irrigation season. Cold water, if applied in large quantities, will lower the temperature of the soil below that which is best for plant growth determined by optimum soil temperature for plant growth. When the soil moisture for plant growth is not lacking, the application of cold irrigation water is a detriment."

Harlan and Anthony (5), working with barley in Idaho, found that a deficiency of water, even after the spikes are losing their color, results in checking the deposit of dry matter. A deficiency of water earlier in the development of the kernel probably determines the size of the kernel even before the rate of deposit of dry matter is checked. They conclude also that late irrigations result in later maturity, and that plants are able to utilize water up to the date of full maturity.

Smith (16), summarizing the work of several workers in Europe and America, states that "Brounoff found that the critical period of oats in respect to moisture is within the ten-day period before heading." He reports also that experiments with rye in Russia show that for the best development of rye abundant moisture and heat are needed before the formation of the heads; that moderate temperature and dry weather during blooming and moisture and warm weather during the ripening period are important. He further states that "All authorities agree that the wheat plant must have an abundance of moisture at the heading stage. Some would place the most critical stage just as the plants are beginning to head, others between the boot and bloom period, and still others between the bloom and milk." Also, "It is agreed by different investigators that wheat needs only sufficient moisture during the first six weeks of its life to keep it growing vigorously." He further shows that there is a positive correlation between the amount of July rainfall and yield of corn for a 25-year period in the following states: Ohio, Indiana, Illinois, Iowa, Nebraska, Kansas, Missouri, and Kentucky. Further studies show a correlation of +0.74 ±0.05 between the amount of rainfall in the 10 days after blossoming in corn and the yield. The correlation coefficient for the amount of rainfall in the 20- and 30-day periods after blossoming and subsequent yield was +0.57 ±0.08 and +0.46 ±0.09, respectively.

Blair (2) found a correlation between the amount of rainfall in May and June and the yield of wheat in North and South Dakota, but none in Minnesota. Smith (16) continued Blair's work for six years and found no marked change in the relation, although he found a slightly lower correlation coefficient in South Dakota between rainfall in May and June and yield of wheat than that obtained by Blair.

Sando (13) compared the rainfall for the different months with the yields of four soft winter wheats grown at College Park, Md. He found that there was a negative correlation between the yield and rainfall for the months of March and May and the yield of the four soft winter wheats for a 12-year period.

Welch (19) presents the results of studies carried out at Gooding, Idaho, where one small irrigation was applied to Dicklow wheat at different stages of growth. The plat receiving an irrigation at "jointing" gave a higher yield than plats receiving no irrigation or plats receiving an irrigation at "heading." The plat receiving one irrigation at "heading" produced grain of better quality which weighed more per measured bushel, indicating that if only one irrigation can be applied it had better be withheld until the crop is in head.

Widtsoe (20), discussing the principles of irrigation, states that "Wheat and the other small grains, peas, beans and similar short-season crops, after having been planted in a soil well filled with moisture, should be allowed to grow as long as possible without irrigation. The early irrigation of such crops is only slightly advantageous, and the results seldom pay for the labor and cost of water. By postponing the first irrigation, the root-system may be more fully developed, so that the best use may be made of the water when it is applied. Such crops grown for seed seldom need irrigation before the time of flowering or seed formation, when one or two moderate irrigations may be applied with decided advantage." Also, that "At the Utah Station it was found that, when a given quantity of water was used, the total weight of the crop was not greatly affected by varying the time of irrigation; the effects were felt in the yields of grain produced. When irrigation was performed early, before flowering, more straw and less seed were produced; when irrigation came late, less straw and more seed resulted. The sum of straw and seed was, in both cases, practically the same. That is, late irrigations make possible the transfer of nutritive materials from the roots and stalks to the heads, there to be permanently elaborated into seed materials. After the seeds are well formed there is seldom any advantage in irrigation. Certain varieties of grain, peas, and beans have an extended growing season, and to such it may be necessary to apply water some time before flowering, and perhaps once after seed-formation is well under way. Even to the crops that mature early, it may often be profitable to add water at the time the seeds are forming most rapidly, for it may help fill them more completely."

Skuderna (18), working with sugar beets at Rocky Ford, Colorado, planted three replications of two series of mother beets. Series I was irrigated when the soil moisture was deficient as indicated by the crop's need for moisture. Series II was maintained at the optimum soil moisture, especially during the blooming period of the plants and also during the development of seed Series I was given three irrigations of approximately 3 inches each and Series II six irrigations of 3 inches each. The average yield of Series I was 1,130 pounds and of Series II, 1,226 pounds. This gives a difference of 96 pounds in favor of maintaining an optimum moisture supply during the flowering period. The germination percentage of seed produced on plats irrigated when the soil moisture was deficient was 81.9%, and on plats maintained at optimum soil moisture 88.2%. The soil moisture data show that the moisture content of both plats was very nearly alike on March 25 and April 7. On May 25, when the plants were blooming and shedding pollen, the soil moisture in Series II was much higher than in Series I. On June 7 the moisture content was slightly higher in Series II but the difference was less than on May 25. This decrease was due to an irrigation applied between the two periods of taking soil samples. On June 25 the moisture content was again much higher in Series II and was still noticeably higher at harvest time. These results indicate that when the moisture content is high during the flowering and filling stage an increased yield of beet seed of higher germination is obtained, while a low moisture content at the flowering and filling stage gives a lower yield of seed with a lower germination.

EXPERIMENTAL METHODS

Studies of the critical periods for irrigation in cereal production were started at the Colorado Experiment Station in the spring of 1917. These studies included work with corn, beans, and wheat. In 1920, the experiment was replanned and since that date has been carried in its present form.

SOIL

The soil at the Colorado Experiment Station at Fort Collins is classified as Billings loam by the United States Bureau of Soils (11). On the experimental plats the soil consists of a loam for a depth of 4 to 5 feet, underlain by a sandy loam subsoil. The color is a reddish gray with a subsoil of a much lighter color. The chemical analysis of the soil and subsoil was made by Headden (10) while conducting experiments on wheat, and undoubtedly there is still an over abundance of the essential plant nutrients in the soil.

STAGE OF DEVELOPMENT OF WHEAT WHEN IRRIGATED

The term "critical period" as used in this paper is the stage in the development of the plant at which an irrigation will increase the yield or when the lack of such an irrigation will decrease the yield. In order to determine which periods in the growth of wheat are critical, six stages in development were arbitrarily chosen as follows: "Germination," "tillering," "jointing," "heading," "blossoming," and "filling." One irrigation was applied at each stage. Fig. 1 shows the development of the plants at the different stages when water was applied.

These different stages may be defined as follows: "Germination" is within six days after the grain has been planted. "Tillering" is when the seedlings begin to send out shoots, sometimes called the stooling stage. "Jointing" is when two joints can be clearly distinguished. "Heading" is when the head is just emerging from the boot. "Blossoming" is when the anthers appear on the head.[4] "Filling" is when the grain is in the late dough.

Four checks were also included in the experiment, as follows: Check 1, "Distributed Irrigation," received the same total amount as put on the critical period plats but in six irrigations of 1-inch each at each of the critical periods. Check 2 received no water. Check 3 received enough water to produce a crop. Check 4 received 1 inch of water at "Germination."

PLAN OF EXPERIMENT

The experiment was carried each year on land which was in summer fallow the previous year. This was found necessary to obtain as uniform a moisture control as possible in the soil used for experimental purposes. It was also necessary to summer fallow in order to eliminate volunteer grain and control the weed crop. Fifty plats were used, each 1/500 acre in size. The plats were laid out in rows (called series) of 10 plats each. No series had two plats which were treated alike.

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[4] At this stage fertilization is usually complete.

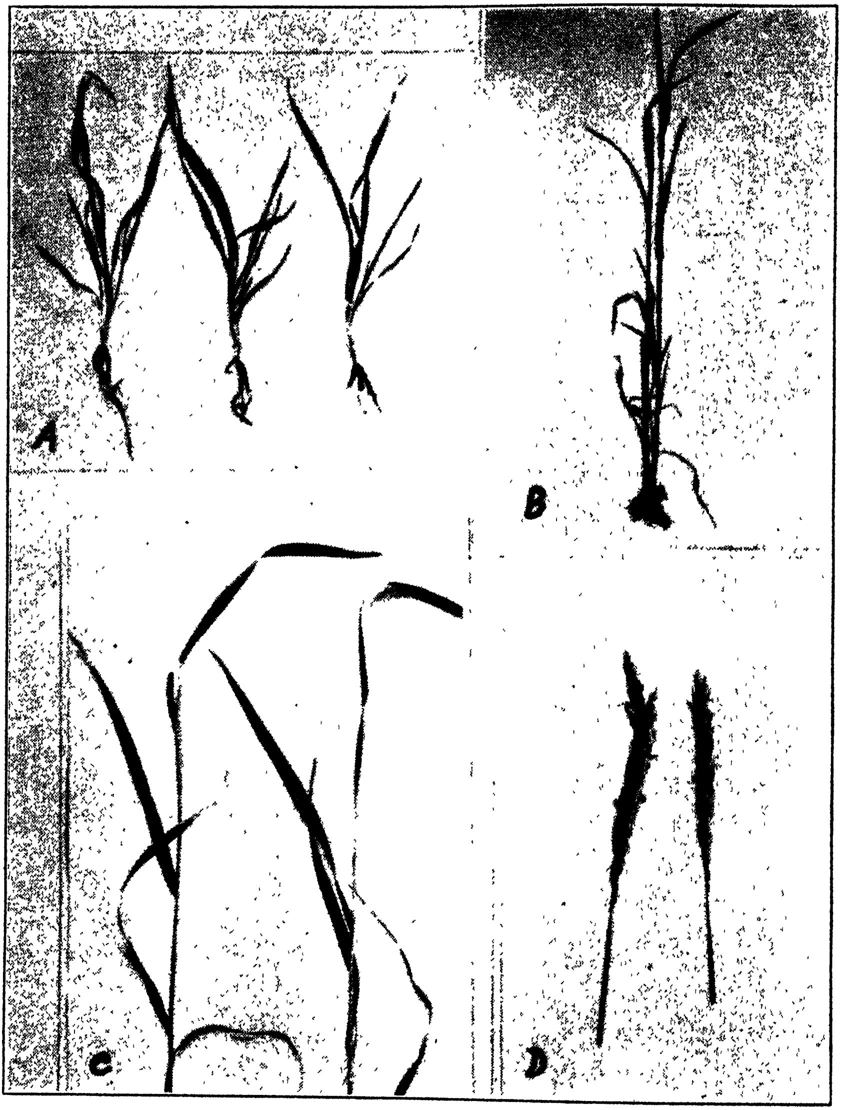
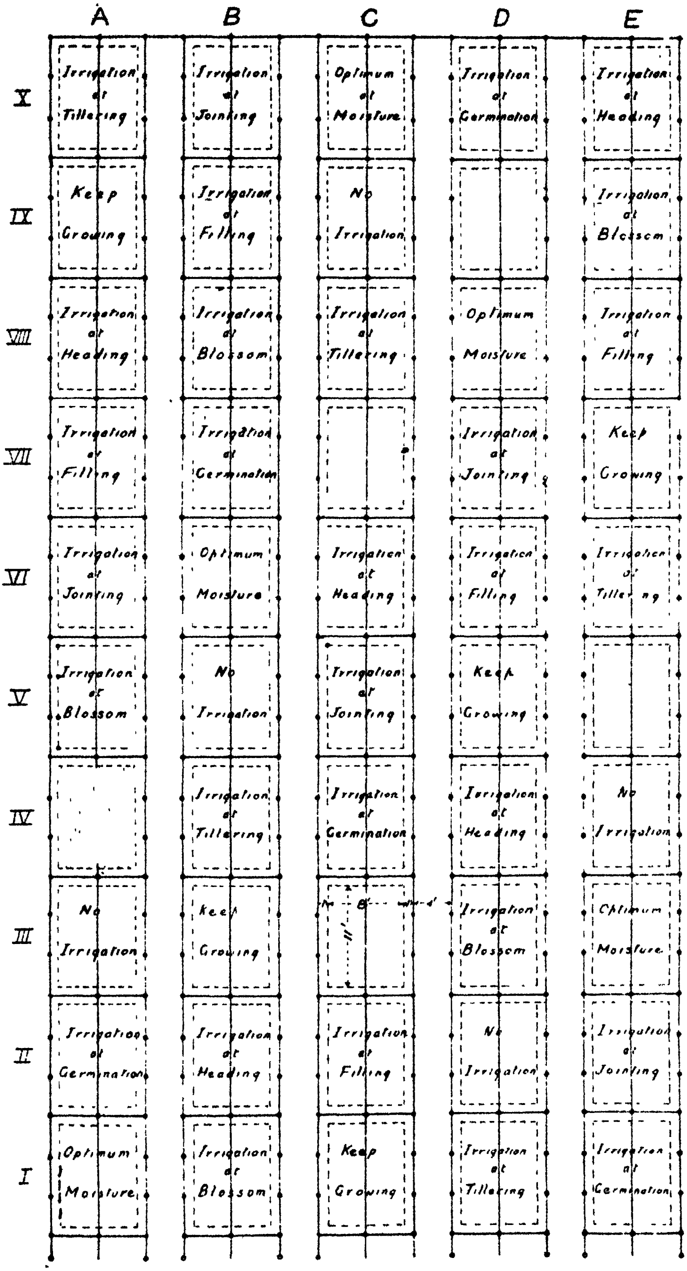


FIG. 1.—Showing the different stages in the growth of the wheat plant at which water was applied. A, tillering; B, jointing; C, heading; D, blossoming.

No two plats receiving the same treatment occupied the same position in any series, with the exception that in 1923 the plats receiving "Distributed Irrigation" were adjacent in Series C and D. In 1920 and 1921, two plats receiving the same treatment occurred in Series A and two in Series C. The plan of the distribution of the plats in



	A	B	C	D	E
X	Irrigation at Tillering	Irrigation at Jointing	Optimum Moisture	Irrigation at Germination	Irrigation at Heading
IX	Keep Growing	Irrigation at Filling	No Irrigation		Irrigation at Blossom
VIII	Irrigation at Heading	Irrigation at Blossom	Irrigation at Tillering	Optimum Moisture	Irrigation at Filling
VII	Irrigation at Filling	Irrigation at Germination		Irrigation at Jointing	Keep Growing
VI	Irrigation at Jointing	Optimum Moisture	Irrigation at Heading	Irrigation at Filling	Irrigation at Tillering
V	Irrigation at Blossom	No Irrigation	Irrigation at Jointing	Keep Growing	
IV		Irrigation at Tillering	Irrigation at Germination	Irrigation at Heading	No Irrigation
III	No Irrigation	Keep Growing		Irrigation at Blossom	Optimum Moisture
II	Irrigation at Germination	Irrigation at Heading	Irrigation at Filling	No Irrigation	Irrigation at Jointing
I	Optimum Moisture	Irrigation at Blossom	Keep Growing	Irrigation at Tillering	Irrigation at Germination

FIG. 2.—Plat plan of critical period experiment, 1920 and 1921, showing arrangement of plats and location of wires and supporting posts.

TABLE 1.—*Arrangement of plats in critical period experiment in 1922 and 1923.*

Plat No.	Series A	Series B	Series C	Series D	Series E	Series F
1922						
I	Distributed	Blossom	Keep growing	Jointing	Germination	
II	Germination	Heading	Filling	No irrigation	Tillering	
III	No irrigation	Keep growing	No irrigation	Blossom	Distributed	
IV	1 inch at germination	Jointing	Germination	Heading	Keep growing	
V	Blossom	No irrigation	Tillering	Keep growing	1 inch at germination	
VI	Tillering	Distributed	Heading	Filling	Jointing	
VII	Filling	Germination	Blossom	Tillering	No irrigation	
VIII	Heading	1 inch at germination	Jointing	Distributed	Filling	
IX	Keep growing	Filling	No irrigation	1 inch at germination	Blossom	
X	Jointing	Tillering	Distributed	Germination	Heading	
1923						
I		No irrigation	Keep growing	No irrigation	Keep growing	No irrigation
II		Germination	Blossom	Filling	Jointing	2 irrigations
III		2 irrigations	Distributed	Distributed	Heading	Germination
IV		Jointing	Heading	Germination	Filling	Tillering
V		Blossom	2 irrigations	Tillering	Distributed	Jointing
VI		Tillering	Jointing	Heading	Blossom	Filling
VII		Filling	Germination	Blossom	Tillering	Distributed
VIII		Heading	Filling	Jointing	2 irrigations	Blossom
IX		Distributed	Tillering	2 irrigations	Germination	Heading
X		Keep growing	No irrigation	Keep growing	No irrigation	Keep growing

1920 and 1921 is shown in Fig. 2. The distribution of the plats in 1922 and 1923 is given in Table 1. In 1923, two extra series were added and were used for the study of soil moisture conditions during the growing season.

Each treatment was replicated four times (five plats). Each series contained a complete set of treatments and four checks.

METHOD OF PLANTING

Marquis wheat which had been previously treated for smut was planted at the rate of 90 pounds per acre. One drill width of 16 rows was planted in each series.

TIME OF PLANTING

Table 2 gives the dates of planting of the critical period experiment for the years 1920 to 1923, inclusive.

TABLE 2.—*Dates of planting and covering of the critical period plats at the Colorado Experiment Station, Fort Collins, for the years 1920 to 1923, inclusive.*

Year	Date planted	Date covered	Rain falling on plats between the date planted and date covered, inches
1920	May 20	June 2	0.30
1921	April 11	April 13	0.00
1922	April 10	April 14	0.17
1923	April 11	April 16	0.00

METHOD OF CONTROLLING MOISTURE

Posts were set up in rows on each side of the series, 1 foot from the edge of the grain. This left a distance of 10 feet from the center of the posts on one side of the series to the center of the posts on the other side of the series. A 4-foot alley was left between adjacent series. In the center of the series posts were set up between the ends of plats. This made in all three rows of posts to each series. The tops of the posts in each row were set level.

The center rows of posts were 5 feet above the ground and 2 feet in the ground. A No. 9 wire was stretched along the center of the top of each row of posts thus forming the ridge of a temporary roof. The outer rows of posts were 2 feet, 6 inches above the ground and 3 feet in the ground. A No. 9 wire was also stretched along the center of the top of each outer row and formed the eaves of the temporary roof. In the earlier experiments, 1920 and 1921, short posts were used for the outer rows but these were found unsatisfactory and were replaced in 1922 by longer posts which are still in use.

The posts in the outer rows were 4 feet, 4 inches apart. In the middle rows the posts were 13 feet apart. Every third post in the outer rows was firmly anchored to the opposite post in the adjacent series by cross wires. The outer rows of the outside series were

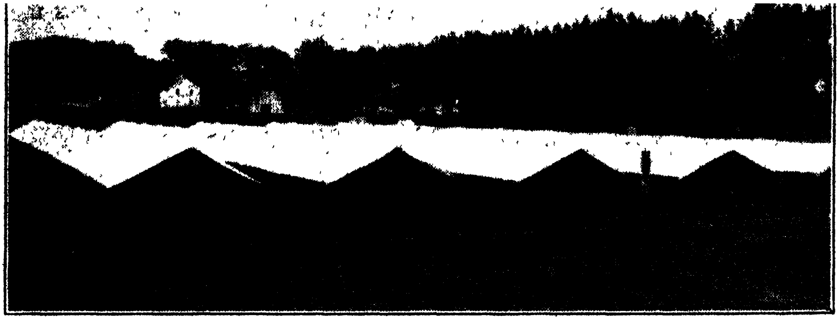


FIG. 3.—End view showing the covers in place in the fall of 1920.

anchored, by wires, to posts buried 3 feet in the ground. This was found necessary to prevent the drawing in of the tops of the posts when subjected to the extra strain of wet canvas covers. The No. 9 wire stretched along the center of the top of each row of posts was drawn tight and anchored to a post buried 5 feet in the ground at each end of each series. Over the wires were stretched heavy (12 oz. duck) canvas covers (11 by 14 feet) with snaps on the long sides which enabled them to be quickly thrown back or stretched at will. Each cover protected an entire plat and lapped slightly over the adjacent plat in the series.

The canvas covers were left on at night and when the weather was wet. See Fig. 3. This prevented any moisture, except that which was purposely added, from reaching the plats. In good weather the covers were folded back so that they were above the space between the ends of the plats. See Fig. 4. Great care was taken to prevent the loss of water from the plats by other means than evaporation and also to prevent unmeasured water from reaching the covered areas. Each plat was thoroughly diked. Banks were set under the edge of the

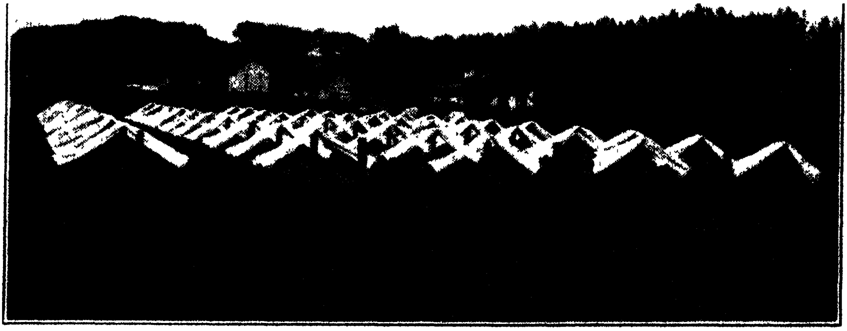


FIG. 4.—End view showing the covers rolled up in the fall of 1920.

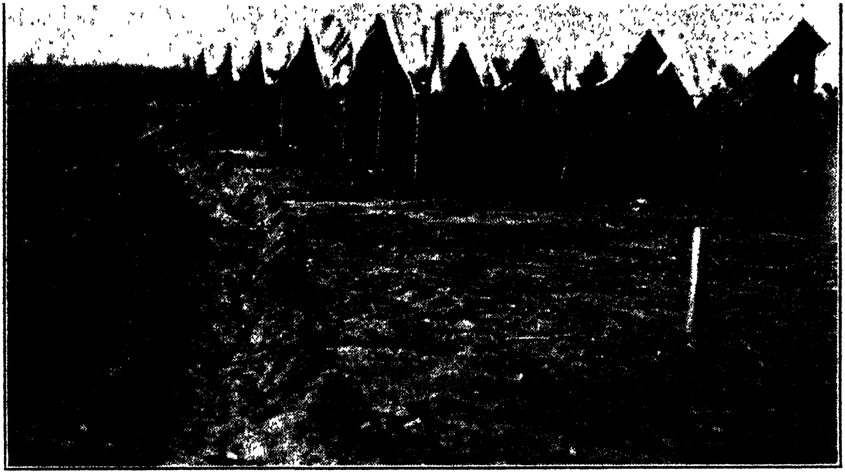


FIG. 5.—End view of series showing the drain which carried the rain off from the alleys. April, 1922.

canvas so that any water falling on the canvas roof-covers might run off into the alleys between the series. These alleys were 4 feet wide. To take care of this water and get it away quickly, ditches having a uniform grade were constructed down the alleys. See Fig. 5. These ditches were connected with a main ditch running across the end of the series which carried the water off into a waste ditch. On July 27, 1923, 2.1 inches of rain fell in 50 minutes. The plats had been previously covered and no moisture from this rainfall penetrated the covered plats, the water falling on the covers being adequately taken care of by the drainage ditches.

Moisture determinations were made on adjacent summer fallow plats in 1922 and 1924. From these determinations it was found that the lateral penetration of moisture in the soil of the Experiment Station at Fort Collins was very slight. Moisture determinations were made 24 hours after water had been standing in a ditch for 5 hours and 50 minutes. Only a slight increase in moisture was found in samples taken 3 feet from the center of the ditch. No increases were found in samples taken 4 feet from the center of the ditch or farther out. In 1924 water stood in the irrigation ditch for four hours. One-foot samples were taken to a depth of 5 feet, 48, 72, 120, and 192 hours after the water had left the ditch. No permanent increase was noticed in any of the samples. In many of the samples a loss was noticed which continued throughout the test. It would seem from the data at hand that any increase found was due to the variation in sampling.

Under conditions on the Experiment Station plats at Fort Collins, water would have to stand over a foot in depth in the alleys for more than four hours before any effect on soil moisture could be noticed from lateral penetration.

Great care was taken in setting up the posts and sinking the anchor posts. All earth removed was returned to the same soil stratum from which it was taken.

SCHEME OF IRRIGATION

Irrigation water was applied in amounts of 6 inches in the years 1920, 1922, and 1923. In 1921 a slight error was caused by a late snow storm. Sufficient snow drifted onto the plats soon after planting to make a measurable amount of water. Immediately after the snow storm sufficient water was added to each plat to make a 1-inch application on all plats at germination. Each plat therefore received 1 inch of water at germination. The later irrigations in 1921 were of 5 inches instead of 6 as in the other years. Inches of irrigation water refer to inches in depth over the area. In 1922, all plats, except the non-irrigated plats, received 1 inch of water at germination. This was found necessary from the results of the previous years. All plats needed sufficient water to germinate the seed and get a uniform stand. The plats which received the irrigation at germination were later given 6 additional inches. The total amount of water applied to the "Distributed" and "Critical Period" plats was 7 inches Table 3 gives the date of irrigation of the differently treated plats for the years 1920 to 1923, inclusive.

TABLE 3.—*Date of irrigation of critical period plats for the years 1920 to 1923, inclusive.*

Irrigation treatment	Date irrigated			
	1920	1921	1922	1923
Germination	———	April 20	April 21	April 17
Tillering	June 25	May 23	May 16	May 16
Jointing	July 1	June 10	June 6	June 2
Heading	July 8	June 21	June 19	June 20
Blossoming	July 13	June 27	June 26	June 29
Filling	July 20	July 6	July 5	July 10
Keep growing	———	April 20	———	———
Distributed[a]	———	———	———	———
No irrigation	———	———	———	———
One inch at germination	———	April 20	April 21	———

[a] The "Distributed" irrigation plats in 1921 and 1923 received 1 inch at "Germination," "Tillering," "Jointing," "Heading," "Blossoming," and "Filling;" and in 1922, the only difference was a 2-inch irrigation at "Germination" instead of a 1-inch irrigation.

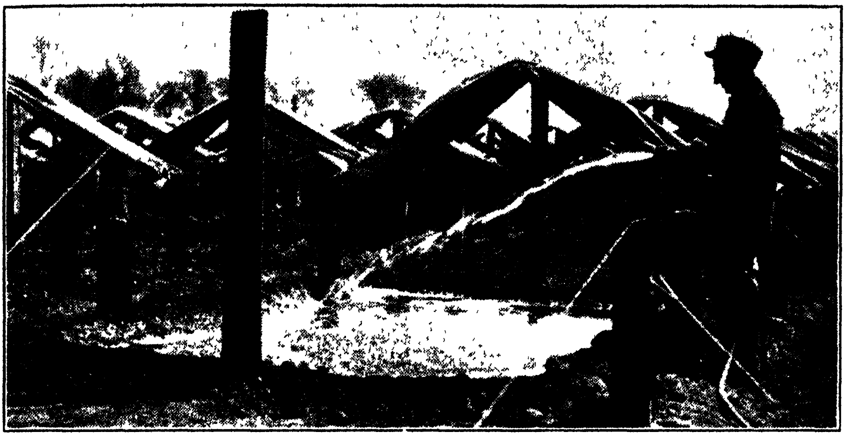


FIG. 6.—Method of irrigating critical period plats. Water being applied to a plat at germination in 1922.

METHOD OF IRRIGATING

The basin method was used throughout. The plats were diked and sufficient water was added to give the required depth. See Fig. 6. The amount of water required for a given depth on the plat was measured in gallons through a water meter. The temperature of the water used in each irrigation in 1922 and 1923 is shown in Table 4.

TABLE 4.—*Temperature of irrigation water used in 1922 and 1923.*

Stage water is applied	Date	Year	Temperature in degrees F	Date	Year	Temperature in degrees F
Germination....	April 22	1922	44	April 17	1923	49
Tillering.......	May 16	1922	50	May 16	1923	48
Jointing.......	June 6	1922	50	June 2	1923	—
Heading.......	June 19	1922	56	June 20	1923	62
Blossoming.....	June 26	1922	60	June 29	1923	60
Filling........	July 5	1922	61	July 10	1923	61

SOURCE OF IRRIGATION WATER

The water used for irrigation was that furnished by the City of Fort Collins for domestic use. It is taken from the Cache la Poudre River above the point where the North Fork flows into the main river.

Headden (9) says, "The Cache la Poudre River flows for the first 50 miles of its course over boulders of schist and granite and then over gravel and sand of the same character." It is from this portion of the river that the domestic water used in Fort Collins comes. There is a slight variation in the solids carried in the water. In the early part of the season the total solids carried by the Fort Collins tap water is lower than it is later in the season when the river is low. As most of the irrigation was done in the early part of the season during the flood water stage, there was less variation than would be found if the plats were irrigated in August and September. It is conceded that a chemical analysis of the irrigation water would have been of value, but as analyses would have to be made at each irrigation it was not considered of sufficient importance in the present experiment to justify the increased expense.

AMOUNT OF WATER APPLIED

Fifty-four and three-tenths gallons of water equals a depth of 1 inch on 1/500 of an acre. For larger amounts this figure was multiplied by the number of inches required and the resulting amount applied.

METHOD OF HARVESTING CROP

Previous experiments by Arny (1) show that where uncropped alleys were left between plats of spring wheat the border effect was noticeable on the yield of the plat when the two outer rows were included, but that very little increase in yield was found when the third row from the outside was included. For this reason in the present experiments the three outside rows and 1 foot from each end were cut and discarded. This left a plat 10 rows wide and 10 feet long to be harvested.

The grain was cut with lawn shears 1 inch above the ground. The area of the trimmed plat was 1/871 of an acre. The cut grain was tied in a sheaf and carefully wrapped in cloth to protect the heads, leafy material, and straw. These sheaves were put in shocks under cover and allowed to cure for three weeks or more. They were then weighed and the grain thrashed. The difference between the grain

TABLE 5.—*Date of ripening of wheat on the differently treated plats.*

Time plats were irrigated	Year	Date ripe	Year	Date ripe	Year	Date ripe	Year	Date ripe
Germination....	1920	Aug. 16	1921	July 28	1922	July 28	1923	Aug. 2
Tillering	1920	Aug. 18	1921	July 29	1922	July 28	1923	Aug. 2
Jointing	1920	Aug. 18	1921	July 28	1922	July 29	1923	Aug. 2
Heading ...	1920	Aug. 19	1921	July 28	1922	Aug. 1	1923	Aug. 2
Blossoming....	1920	Aug. 19	1921	July 28	1922	Aug. 1	1923	Aug. 2
Filling ...	1920	Aug. 20	1921	July 28	1922	July 28	1923	Aug. 2
Distributed....	1920	Aug. 18	1921	July 30	1922	Aug. 1	1923	Few days later[a]
No irrigation...	1920	Aug. 16	1921	July 28	1922	July 28	1923	Few days later[a]
Keep growing...	1920	Aug. 16	1921	July 28	1922	July 28	1923	Few days later[a]
One inch at germination..	1920	Aug. 16	1921	July 28	1922	July 28	1923	Few days later[a]

[a] Because of an oversight the exact date was not taken.

weight and the total weight of grain and straw was used as the straw yield.

DATE OF RIPENING

Table 5 shows the date of ripening of the wheat on the different plats.

The date of ripening was slightly changed by the time of application of water in 1920, 1922, and 1923. There was little, if any, difference in 1921. In 1920, the plats which received no irrigation ripened earliest, August 16. Those which received a 6-inch irrigation at "tillering" or "jointing" ripened two days later on August 18. The plats which received a 6-inch irrigation at "heading" or "blossoming" ripened on August 19. Those which were given a 6-inch irrigation at "filling" ripened on August 20. In 1922, plats which received a 6-inch irrigation at "heading," "blossoming," or a "distributed irrigation" ripened four days later than the earliest ripening plats. Those which received no water or 6 inches at "germination" or "tillering" ripened earliest. The plats irrigated at "jointing" ripened on July 29. The plat receiving an irrigation at "filling" ripened with the plats irrigated at "tillering" or "germination." In 1923, all plats ripened at the same time with the exception of those receiving a "distributed irrigation." These ripened a few days later.

YIELDS AND QUALITY OF GRAIN HARVESTED

Tables 6, 7, and 8 give the yields of grain, of straw, and of total crop, in grams, for all plats in the experiment for the years 1921 to 1923, inclusive. The weight per measured bushel and the weight per thousand kernels of the grain are shown in Tables 9 and 10. The calculated odds that the observed differences are significant are shown in Table 11. The data for 1920 are omitted because of irregularities in treatment. In 1920, the plats were sown late and were not covered until June 2. They received 0.3 inch of rain before they were covered. No irrigation water was applied to any plats until the grain had tillered. In 1923, Series F was left out of the interpretation of results, because several plats in this series were partially flooded early in the season due to imperfect canvas covers. Consequently, the results were not comparable.

YIELD OF GRAIN

It will be seen from the data shown in Table 6 that the highest yield was obtained on the plats receiving 6 or 7 inches of water "distributed" over the growing period. The plats receiving "distributed irrigations" outyield the plats irrigated at "jointing" by 134.6 grams. The "jointing" plat yields the highest of the plats

TABLE 6.—*Yield of grain in grams per plat for the years 1921 to 1923, inclusive.*

Year	Plat	Irrigation at						Irrigations	No	Irrigations to	Irrigation of 1 inch
		Germination	Tillering	Jointing	Heading	Blossoming	Filling	distributed	irrigation	keep growing	at germination
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
1921	A	294	234	351	276	256	170	409	115	152	182
	B	182	155	281	236	129	123	247	75	183	129
	C	206	232	202	191	254	159	410	67	251	104
	D	376	248	271	204	228	190	279	156	245	97
	E	272	257	265	340	254	192	313	118	221	117
1922	A	302	417	495	381	340	293	570	258	249	260
	B	359	459	366	431	327	277	620	238	266	244
	C	275	332	408	400	339	271	616	234	288	236
	D	432	341	396	366	299	276	541	215	249	254
	E	338	312	366	442	354	231	524	232	225	234
1923	B	470	513	602	573	496	405	837	495[a]	566[a]	
	C	519	561	635	644	527	440	821	567[a]	512[a]	
	D	434	563	593	572	488	372	729	504[a]	553[a]	
	E	481	346	539	530	460	352	737	516[a]	425[a]	
3-year total		4,940	4,970	5,770	5,586	4,751	3,751	7,653	3,790	4,385	1,857
3-year average		352.9	355	412	399	339.3	268	546.6	271	313	186

[a] Plat yields high, moisture drifted onto plats during season.

receiving a single irrigation. The chances that the difference between the "distributed" and "jointing" plats is significant are over 10,000 to 1. These odds were calculated by Student's method as presented by him (17) and by Love (12).

From Table 6 it will be seen that the plats receiving only one irrigation decreased in yield in the following order: "Jointing," "heading," "tillering," "germination," "blossoming," and "filling." The odds that the difference between "jointing" and "heading" is significant are 3.9 to 1. (See Table 11.) The chances that the difference of 57 grams between "jointing" and "tillering" is significant are 207 to 1. The odds that the difference between "heading" and "tillering" is significant are 68 to 1. The chances that the difference of 36 grams between "heading" and "germination" is significant are 26.7 to 1. The difference between the yield of the "tillering" and "germination" plats is 2.1 grams. The odds that such a difference is significant are less than 1 to 1. The odds that the difference between the yield at "tillering" and "blossoming" of 15.7 grams is significant are 4.7 to 1. The difference between the yield at "germination" and "blossoming" is 13.6. The odds that this difference is significant are 3.2 to 1. The plats receiving an irrigation at "tillering" yield 87 grams more than the next lowest yielding plat (irrigation at "filling"). The odds that this difference is significant are over 10,000 to 1.

From the above it will be seen that the highest yielding plats were those receiving a "distributed irrigation." The highest yielding plats receiving a single irrigation were the plats irrigated at "jointing." The plats irrigated at "heading" yielded a little less, but there was not sufficient difference to draw definite conclusions. The plats irrigated at "tillering" or "germination" yielded less than the plats irrigated at "jointing" or "heading." The difference between "tillering" and "germination" was so small that there was no real significance between the two. When water was applied at the filling stage it was of little benefit in increasing the yield of the wheat crop to which it was applied.

YIELD OF STRAW

Table 7 shows the yield of straw in grams for all plats in the experiment for the years 1921 to 1923, inclusive, with the exception of Series A and G in 1923 which were used for soil studies and Series F which was discarded on account of faulty covers. In 1920 no straw yields were taken.

It will be seen from Table 7 that the yields of straw of the differently treated plats decreased in the following order: "Distributed," "jointing," "tillering," "germination," "heading," "blossoming," "keep

TABLE 7.—*Yield of straw in grams per plat for the years 1921 to 1923, inclusive.*

Year	Series	Irrigation at						Irrigations distributed	No irrigation	Irrigations to keep growing	Irrigations of 1 inch at germination
		Germination	Tillering	Jointing	Heading	Blossoming	Filling				
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
1921	A	917	1,070	688	572	516	416	874	311	494	618
	B	675	453	819	546	296	383	585	242	390	400
	C	751	584	614	464	543	350	890	170	649	322
	D	928	902	685	588	589	533	667	380	537	326
	E	873	711	641	890	645	492	713	322	608	528
Average		829	744	689	612	520	435	746	285	536	439
1922	A	544	941	950	725	609	588	842	514	521	516
	B	708	846	680	698	526	523	1,153	417	469	491
	C	556	653	756	683	544	440	978	434	473	426
	D	638	702	694	600	484	519	880	397	494	515
	E	562	591	701	700	581	416	847	479	368	434
Average		602	747	756	681	549	497	940	448	465	476
1923	B	1,026	1,115	1,272	1,088	911	820	1,574	896	1,026	
	C	1,022	1,313	1,296	1,313	1,016	942	1,690	1,022	926	
	D	999	1,185	1,183	999	894	798	1,563	906	1,017	
	E	851	852	1,162	1,026	855	625	1,462	923	786	
Average		974	1,116	1,228	1,106	919	796	1,572	937	939	
3-year total		11,050	11,918	12,141	10,892	9,009	7,845	14,718	7,413	8,758	4,576
3-year average		789.3	851.3	867.2	778	643.5	560.4	1,051.3	529.5	625.5	458[a]

[a] Average of 10 plats.

growing," and "filling." "Distributed" irrigation gave the highest straw yield and the highest grain yield. The difference between the plat receiving a "distributed irrigation" and the plat receiving an irrigation at "jointing" was 184.1 grams. The odds that such a difference is significant are 458 to 1. (See Table 11.)

The highest average yield of straw in the plats receiving a single irrigation was found in the plats irrigated at "jointing." The difference in yield between the plats irrigated at "jointing" and those irrigated at "tillering" was 15.9 grams. The odds that this difference is significant are less than 1 to 1. The difference between the plats receiving an irrigation at "jointing" and those receiving an irrigation at "germination" was 77.9 grams. The odds that this difference is significant are 8.85 to 1.

The plats receiving an irrigation at "heading" yielded less straw than those receiving an irrigation at "germination." The difference in yield between the plats receiving an irrigation at "jointing" and those receiving an irrigation at "heading" was 89.2 grams. The odds that this difference is significant are 81.8 to 1.

The differences in yield of straw between the plats receiving an irrigation at "tillering" and those receiving an irrigation at "germination" and "heading" were 62 grams and 73.3 grams, respectively. The odds that such differences are significant are 8.75 to 1 in the former and 10.3 to 1 in the latter. The difference in average yield of straw between the plats receiving an irrigation at "tillering" and those receiving an irrigation at "blossoming" was 207.8 grams. The odds that this difference is significant are 7,899 to 1. The plats receiving an irrigation at "germination" yielded 11.3 grams more than the plats receiving an irrigation at "heading." The odds that this difference is significant are less than 1 to 1. The differences in yield of straw between the plats receiving irrigations at "germination" and "heading" and the plats receiving an irrigation at "blossoming" were 145.8 grams and 134.5 grams. The odds that such differences are significant are 618 to 1 in the former and 9,999 to 1 in the latter. The remaining plats receiving 6 inches or more at an irrigation differed in yield of straw from the plat receiving an irrigation at "blossoming" by 83.1 grams. The odds that such a difference is significant are 102 to 1. This latter plat yielded very little over the check which received no water, the difference being too small to be significant.

From the above it will be seen that the highest yield of straw was obtained on the plat receiving irrigations "distributed." The highest yield of straw on the plats receiving one irrigation was at the "jointing" period. Plats receiving water after this period decreased in

TABLE 8.—*Yield of grain and straw in grams per plat for the years 1921 to 1923, inclusive.*

Year	Plat	Irrigation at Germination	Tillering	Jointing	Heading	Blossoming	Filling	Irrigations distributed	No irrigation	Irrigations to keep growing	Irrigation of 1 inch at germination
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
1921	A	1,211	1,304	1,039	848	772	586	1,283	426	646	800
	B	857	608	1,100	782	425	506	832	317	573	529
	C	957	816	816	655	797	509	1,300	237	900	426
	D	1,304	1,150	956	792	817	723	946	536	782	423
	E	1,145	968	906	1,230	899	684	1,026	440	829	645
Total		5,474	4,846	4,817	4,307	3,710	3,008	5,387	1,956	3,730	2,823
Average		1,094.8	969.2	963.4	861.4	742.0	601.6	1,077.4	391.2	746	564.6
1922	A	846	1,358	1,445	1,106	949	881	1,412	772	770	777
	B	1,068	1,305	1,046	1,129	853	800	1,773	655	735	735
	C	831	985	1,164	1,083	883	711	1,594	668	761	661
	D	1,070	1,043	1,090	966	783	795	1,421	612	743	769
	E	900	903	1,067	1,142	935	647	1,371	711	593	668
Total		4,715	5,594	5,812	5,426	4,403	3,834	7,571	3,418	3,602	3,610
Average		943.0	1,118.8	1,162.4	1,085	880.6	766.8	1,514.2	683.6	720.4	722
1923	B	1,496	1,628	1,874	1,661	1,407	1,225	2,411	1,391	1,592	
	C	1,541	1,874	1,931	1,957	1,543	1,382	2,511	1,589	1,438	
	D	1,433	1,748	1,776	1,571	1,382	1,170	2,292	1,410	1,570	
	E	1,332	1,198	1,701	1,556	1,315	977	2,199	1,439	1,211	
Total		5,802	6,448	7,282	6,745	5,647	4,754	9,413	5,829	5,811	
Average		1,450.5	1,613	1,820.5	1,686.25	1,411.75	1,188.5	2,353.2	1,457.25	1,452.7	
3-year total		15,991	16,888	17,911	16,478	13,760	11,596	22,371	11,203	13,143	6,433
3-year ave.		1,142.2	1,206.2	1,279.8	1,177	982.8	828.3	1,597.9	800.2	938.8	643.3

TABLE 9.—*Weight per measured bushel.*

Year	Series	Irrigation at Germination	Tillering	Jointing	Heading	Blossoming	Filling	Irrigations distributed	Irrigations to keep growing	Irrigations of 1 inch at germination	No irrigation
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1921	A	60.00	58.50	59.00	60.00	61.50	61.00	61.50	58.00	58.25	60.25
	B	57.75	58.00	57.50	60.25	62.00	61.00	60.00	59.25	58.50	——
	C	57.25	59.50	59.00	60.50	60.75	61.50	60.00	60.25	59.00	——
	D	58.00	58.50	57.00	59.50	60.25	60.00	60.25	59.50	——	60.00
	E	59.50	58.00	59.00	60.50	61.00	60.00	60.25	60.00	——	60.00
Total		292.50	292.50	291.50	300.75	305.50	303.50	302.00	297.00	175.75	180.25
Average		58.50	58.50	58.30	60.15	61.10	60.70	60.40	59.40	58.58	60.08
1922	A	60.25	60.00	58.00	61.50	62.75	61.50	62.75	59.75	60.50	61.00
	B	60.75	60.75	60.25	63.50	62.75	61.00	62.00	60.25	59.75	61.50
	C	59.00	59.75	60.25	62.50	63.00	62.25	62.00	61.50	61.00	60.50
	D	62.00	59.75	60.75	61.50	61.25	62.50	60.50	59.25	60.00	60.25
	E	61.00	60.75	60.25	63.25	63.00	61.50	62.50	61.25	61.25	61.00
Total		303.00	301.00	299.50	312.25	312.75	308.75	309.75	302.00	302.50	304.25
Average		60.60	60.20	59.90	62.45	62.55	61.75	61.95	60.40	60.50	60.85
1923	B	59.75	60.00	59.75	62.00	62.00	61.25	61.00	62.50	——	61.00
	C	60.00	59.00	60.00	62.00	62.00	60.50	61.00	62.00	——	61.25
	D	59.75	60.00	60.50	62.00	62.50	58.50	61.00	62.00	——	61.00
	E	60.00	58.25	58.75	61.00	61.75	60.75	61.00	60.50	——	61.50
Total		239.50	237.25	239.00	247.00	248.25	241.00	244.00	247.00	——	244.75
Average		59.87	59.30	59.75	61.75	62.06	60.25	61.00	61.75	——	61.19
3-year total		835.00	830.75	830.00	860.00	866.50	853.25	855.75	846.00	478.25	729.25
3-year ave.		59.60	59.30	59.30	61.40	61.90	60.90	61.10	60.40	59.78	60.80

yield of straw. The earlier irrigated plats, "germination" or "tillering," had a straw yield slightly lower than the plats irrigated at "jointing," but the difference was very slight.

WEIGHT PER MEASURED BUSHEL

The weight per measured bushel was influenced by the later applications of water. Table 9 gives the weight per measured bushel for the three-year period, 1921 to 1923, inclusive. The heaviest weight per measured bushel was found on the plats irrigated at "blossoming." Bushel weight decreased in weight in the following order: "Distributed," "heading," "filling," "no irrigation," "keep growing," "germination," "tillering," and "jointing."

There was little difference in weight per bushel between the last three treatments. The difference in bushel weight between irrigations at "germination" and "jointing" and "tillering" was 0.3 of a pound. The odds that such a difference is significant are 4.43 to 1 for "germination" and "tillering." The odds that the difference between "germination" and "jointing" is significant are 7.47 to 1. The difference in bushel weight between the "germination" and "no irrigation" plat was 1.2 pounds. The odds that such a difference is significant are 47.1 to 1. The difference between "tillering" and "no irrigation" was 1.5 pounds. The odds that this difference is significant are over 10,000 to 1. The difference between "jointing" and "no irrigation" was 1.5 pounds. The chances that this difference is significant are 1,089.8 to 1. The difference between "germination" and heading was 1.8 pounds. The chances that this difference is significant are over 10,000 to 1. The difference between the weight per measured bushel of plats irrigated at "germination" and at "blossoming" was 2.3 pounds. The chances that this difference is significant are over 10,000 to 1. There was a difference of 0.5 pound between the weight per measured bushel at "heading" and the weight per measured bushel at "blossoming." The chances that this difference is significant are 65.5 to 1. The differences between the bushel weight of the plats irrigated at "blossoming" and "filling" and the "distributed" and the "no irrigation" plats were 1, 0.8, and 1.1 pounds, respectively. The chances that these differences are significant are 167.8 to 1, over 10,000 to 1, and over 10,000 to 1, respectively. The differences in bushel weight between the plats receiving an irrigation at heading and the bushel weight of grain from the plats receiving treatments at "filling" "distributed," and "no irrigation" were 0.5, 0.3, and 0.6 pound, respectively. The odds that these differences are significant are 7.47 to 1, 7.47 to 1, and 172.2 to 1, respectively.

When considering the increase in bushel weight of grain from the plats receiving a "distributed irrigation," the following differences were found, 0.2 and 0.3 pounds between the "distributed irrigation" plats and the "filling" and "no irrigation" plats. The odds that the above differences are significant are 2.47 to 1 for the former and 59.9 to 1 in the latter.

WEIGHT PER 1,000 KERNELS

Table 10 gives the weight per 1,000 kernels. Table 11 gives the odds of significance of the differences between the weights of the differently treated plats. The kernel weight varied with the different treatments in the following order from the heaviest to the lightest: "Heading," "blossoming," "distributed," "filling," "jointing," "tillering," and "germination." The plats used as checks receiving either no measured water during the growing period or just sufficient to produce a crop were left out of this discussion. The 1923 weights were increased by unmeasured water drifting onto the check plats.

In considering the differences in weight per 1,000 kernels it was found that on the plat receiving an irrigation at "heading" 1,000 kernels weighed 0.25 gram more than the plat receiving an irrigation at "blossoming." The odds that this difference is significant are less than 1 to 1. Considering the significance of a difference of 0.3 gram between the plats irrigated at "heading" and those receiving a "distributed irrigation," odds of 2.33 to 1 are obtained. The difference in weight per 1,000 kernels between the plats receiving an irrigation at "heading" and the plats irrigated at "filling" was 3.45 grams. The odds that this difference is significant are 2,107 to 1. When the plats irrigated at heading were compared with plats irrigated at different periods, the following differences in weight per 1,000 kernels were found for the following treatments: "Jointing," 3.73 grams; "tillering," 4.67 grams; and "germination," 4.90 grams. The odds that these differences are significant are over 10,000 to 1 in each case.

The differences in weight per 1,000 kernels between the plats receiving an irrigation at "blossoming" and the plats receiving other treatments were as follows: "Distributed," 0.05 gram; "filling," 3.20 grams; "jointing," 3.48 grams; "tillering," 4.42 grams; and "germination," 4.65 grams. The odds that these differences in weight per 1,000 kernels are significant are less than 1 to 1 for the difference between the plats irrigated at "blossoming" and those receiving a "distributed irrigation" and over 10,000 to 1 for the other treatments.

The differences in weight per 1,000 kernels between the plats receiving irrigation water "distributed" and the plats irrigated at

TABLE 10.—*Weight per 1,000 kernels for the differently treated plats for a three-year period from 1921 to 1923, inclusive.*

Year	Series	Irrigation at						Irrigations distributed	No irrigation	Irrigations to keep growing	Irrigations of 1 inch at germination
		Germination	Tillering	Jointing	Heading	Blossoming	Filling				
		Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
1921	B	19.89	22.80	21.99	24.16	26.16	24.31	24.86	21.44	20.59	21.71
	C	21.84	22.04	22.42	25.48	25.36	23.84	26.22	21.63	23.07	22.65
	D	22.12	22.90	21.52	24.83	24.87	23.94	25.20	21.48	21.79	22.30
Total		63.85	67.74	65.93	74.47	76.39	72.09	76.28	64.55	65.45	66.66
Average		21.28	22.58	21.98	24.82	25.46	24.03	25.43	21.52	21.82	22.22
1922	B	21.21	22.42	21.12	25.85	25.84	20.87	27.66	21.25	20.53	19.21
	C	19.28	20.02	21.94	24.92	26.00	21.64	27.33	19.67	21.47	19.89
	D	21.43	19.52	21.43	25.86	25.17	22.98	25.68	19.50	20.72	19.73
Total		61.92	61.96	64.49	76.63	77.01	65.49	80.67	60.42	62.72	58.83
Average		20.64	20.65	21.50	25.54	25.67	21.83	26.89	20.14	20.91	19.61
1923	B	23.69	23.69	24.86	29.37	28.32	23.69	27.25	25.73	27.28	
	C	23.86	22.89	25.66	29.63	28.56	24.92	27.15	27.30	27.33	
	D	23.39	24.81	26.51	29.80	27.56	22.61	26.95	26.58	26.79	
	E	23.45	21.44	24.44	29.33	28.87	25.88	27.94	26.79	26.89	
Total		94.39	92.83	101.47	118.13	113.31	97.10	109.29	106.40	108.29	
Average		23.59	23.20	25.36	29.53	28.32	24.27	27.32	26.60	27.07	
3-year total		220.16	222.53	231.89	269.23	266.71	234.68	266.24	231.37	236.46	125.49
3-year ave.		22.02	22.25	23.19	26.92	26.67	23.47	26.62	23.14	23.65	20.92

TABLE 11.—*Odds on the significance of the differences in yield between the differently treated plats.*

(Calculated by Student's method.)

Differences between irrigations at	Odds that the differences are significant for			
	Grain yield	Straw yield	Weight per 1,000 kernels	Weight per measured bushel
Germination and tillering	Less than 1.0 to 1	8.75 to 1	Less than 1.00 to 1	4.43 to 1
Germination and jointing	93.0 to 1	8.85 to 1	136.30 to 1	7.47 to 1
Germination and heading	26.7 to 1	Less than 1.00 to 1	Over 10,000.00 to 1	Over 10,000.00 to 1
Germination and blossoming	3.2 to 1	618.00 to 1	Over 10,000.00 to 1	Over 10,000.00 to 1
Germination and filling	Over 10,000.0 to 1	6,879.00 to 1	125.30 to 1	374.00 to 1
Germination and distributed	Over 10,000.0 to 1	397.00 to 1	10,000.00 to 1	5,999.00 to 1
Tillering and jointing	207.0 to 1	Less than 1.00 to 1	18.30 to 1	Less than 1.00 to 1
Tillering and heading	67.5 to 1	10.30 to 1	Over 10,000.00 to 1	Over 10,000.00 to 1
Tillering and blossoming	4.7 to 1	7,899.00 to 1	Over 10,000.00 to 1	Over 10,000.00 to 1
Tillering and filling	Over 10,000.0 to 1	Over 10,000.00 to 1	20.70 to 1	9,999.00 to 1
Tillering and distributed	Over 10,000.0 to 1	184.00 to 1	Over 10,000.00 to 1	Over 10,000.00 to 1
Jointing and heading	3.9 to 1	81.80 to 1	Over 10,000.00 to 1	Over 10,000.00 to 1
Jointing and blossoming	5,554.0 to 1	Over 10,000.00 to 1	Over 10,000.00 to 1	Over 10,000.00 to 1
Jointing and filling	Over 10,000.0 to 1	Over 10,000.00 to 1	2.56 to 1	2,832.00 to 1
Jointing and distributed	Over 10,000.0 to 1	458.00 to 1	Over 10,000.00 to 1	Over 10,000.00 to 1
Heading and blossoming	2,499.0 to 1	9,999.00 to 1	Less than 1.00 to 1	65.50 to 1
Heading and filling	Over 10,000.0 to 1	Over 10,000.00 to 1	2,107.00 to 1	7.47 to 1
Heading and distributed	Over 10,000.0 to 1	5,999.00 to 1	2.33 to 1	7.47 to 1
Blossoming and filling	Over 10,000.0 to 1	102.00 to 1	Over 10,000.00 to 1	167.80 to 1
Blossoming and distributed	Over 10,000.0 to 1	Over 10,000.00 to 1	Less than 1.00 to 1	Over 10,000.00 to 1
Filling and distributed	Over 10,000.0 to 1	Over 10,000.00 to 1	3,332.00 to 1	2.47 to 1

"filling," "jointing," "tillering," and "germination" were 3.15 grams, 3.43 grams, 4.37 grams, and 4.60 grams, respectively. The odds that these differences are significant are 3,332 to 1 for the plats receiving irrigation at "filling" and over 10,000 to 1 for the other treatments. The differences in weight per 1,000 kernels between the plats receiving an irrigation at "filling" and those receiving an irrigation at "jointing," "tillering," and "germination" were 0.28 gram, 1.22 grams, and 1.45 gram, respectively. The odds that these differences are significant are 2.56 to 1, 20.7 to 1, and 125.3 to 1, respectively.

The differences in weight per 1,000 kernels between the plat receiving an irrigation at "jointing" and plats receiving irrigations at "tillering" and "germination" were 0.94 gram and 1.17 gram, respectively. The odds that these differences are significant are 18.3 to 1 and 136.3 to 1, respectively. The difference in weight per 1,000 kernels between the plats receiving irrigations at "germination" and "tillering" is 0.23 gram. The odds that this difference is significant are less than 1 to 1.

The weight per 1,000 kernels indicates some characters of the grain which are not brought out in the bushel weight. The grain from the plats receiving an irrigation at "germination" and "tillering" was light in weight and when examined was found to be badly shriveled. The grain from the plats receiving an irrigation at "jointing" also was light in weight. The kernels were long and poorly filled but were not shriveled or shrunken. The grain from the plats receiving an irrigation at "filling" weighed slightly more per 1,000 kernels than the grain from the plat irrigated at "jointing." The kernels were much smaller but were short, plump, and well filled. When comparing Table 9 and Table 10 it will be seen that the weight per 1,000 kernels follows fairly closely the weight per measured bushel.

SOIL MOISTURE

Soil moisture samples were taken at planting time (April) to determine whether the moisture condition of the plats was uniform. Three sets were taken in each series, one at each end and one in the center between plats 5 and 6. These samples were taken in 1-foot sections, with the exception of the first foot which was taken in 6-inch sections. The soil samples were taken to a depth of 5 feet. In the fall as soon after harvest as possible samples were again taken in each of the plats and moisture determinations made. These data are so voluminous that it seems best to omit them from this report; but the following general statements concerning the conditions found may be made.

The moisture content of the soil was lower in 1921 than in 1922 or 1923 and this evidently had some influence on the low yields obtained that year. The moisture content varied in some plats. In 1921, the center series had a higher moisture content than either the north or south ends of the block. In 1922, there was very little variation within the series or between the series. With few exceptions the differences were very slight. In 1923, the moisture content as a whole was higher than in the other two years and the yield shows the benefit of the additional moisture. Plat 10 showed a slightly lower moisture content in the fourth and fifth foot than either of the other plats. However, outside of the fourth foot in plat 5 Series E and plat 1 Series B there was no great fluctuation in the soil moisture content.

The moisture content of the plats in the fall of 1921, 1922, and 1923 was determined also. It was found that where only one irrigation was applied the crops from the plats irrigated at the earlier periods used more of the applied water than did the crops from the plats which received the later applications.

The moisture content of the fourth and fifth foot varied but little. An increase in the moisture content of the soil at the end of the season was found in the plats receiving an irrigation at "jointing," "heading," "blossoming," and "filling." The plats receiving "no water," 1 inch at "germination," 6 inches at "germination," 6 inches at "tillering," and 6 inches "distributed" showed little variation in the third and fourth foot sections, although the third foot varied more than any of the other sections. It was higher in moisture content in the checks and in the early irrigation plats than in any other section but did not increase in the same proportion from "tillering" to "filling" as some of the other sections. The second foot showed a marked increase in moisture content from "tillering" to "filling," being high at the "filling" stage. It is evident that much of the water put on at this period was not used by the wheat crop. The second 6-inch section showed a similar increase but not to so great an extent as the second foot. The surface 6 inches was very dry for all treated and untreated plats, but the moisture content increased slightly from "heading" to "filling." The same condition existed in each of the three years in which soil samples were taken in the fall. These results indicate that stored water may have some effect on the following crop. The experiment has not been carried long enough to draw definite conclusions on this point.

RESIDUAL EFFECT OF WATER ON THE FOLLOWING CROP

In 1922 and 1923, bulk crops of Marquis wheat were grown on the plats where the critical period experiments were carried in 1921 and

1922. One square yard was harvested from each of the plats which had been treated differently the previous year. No irrigation water was applied to the plats in the year the bulk crop was sown. The only moisture added was that which fell as rain or snow. The precipitation from the time the canvas covers were removed in the fall of 1921 to harvest in 1922 was 11.55 inches. The precipitation in the same period in 1922 and 1923 was 24.17 inches. The yields of straw and grain are given in Table 12 for the two years the experiment was conducted.

It will be seen that there was an increased yield in both years between the plats irrigated at "heading," "blossoming," or "filling" and the plats irrigated at "germination," "tillering," or "jointing." The difference in yield in 1922 between the square yards harvested from the plats irrigated at "jointing" and "blossoming" in 1921 was very slight. In 1923, the rainfall for the 12 month period, August, 1922, to July, 1923, was 24.17 inches. As in the previous case, when wheat was grown on land following the critical period treatments of the previous year, the yield increased in the following order: "Germination," "tillering," "jointing," "blossoming," and "filling." The straw yields followed the same trend with the exception of the plat receiving irrigation water at "tillering." This plat gave a higher average yield than the "jointing" plat. These data indicate that water applied later than the jointing stage is not entirely used by that year's wheat crop, and that part of the moisture is available to a crop grown on the same land the following year. No definite conclusions are drawn here as the data cover only a two-year period. Further studies will be reported later

POTOMETER EXPERIMENT

Parallel with the field plats a set of experiments was conducted in potometers. The potometers consisted of double containers, one fitting inside the other, with an air space between the walls. The inner container was of black iron coated with "gas tar" and the outer container was of galvanized iron. The inner container was 5 feet deep and 14 inches in diameter (inside measurement). The outer galvanized iron container was 5 feet deep and 17 inches in diameter. This left a dead-air space between the outer and inner container of slightly under 1½ inches. The potometers were placed in a straight trench 5 feet in depth. Each potometer was 1½ feet from the adjacent one in the trench. The earth from the trench was carefully thrown out in sections consisting of the first 6 inches, the second 6 inches, the second foot, the third foot, and the fourth and fifth foot. Each container was carefully filled with soil placed in the same

TABLE 12.—*Yields of straw and grain from 1 square yard in 1922.*

Taken from bulk crop grown on land occupied by critical period plats in 1921 and the 1923 yields for the bulk crop grown on the 1922 critical period plat.

Irrigated in 1921 at	Grain yield in grams Series							Straw yield in grams Series						
	A	B	C	D	E	Total	Average	A	B	C	D	E	Total	Average
Germination	51	86	106	91	95	429	85.8	80	119	134	127	134	594	118.8
Tillering	80	108	91	89	95	463	92.6	117	155	125	129	153	679	135.8
Jointing	91	109	102	125	94	521	104.2	150	161	145	172	134	762	152.4
Heading	106	136	138	139	146	665	133.0	151	186	193	197	206	933	186.6
Blossoming	105	111	95	100	129	540	108.0	156	154	144	156	182	792	158.4
Filling	125	140	126	119	117	627	125.4	182	206	199	197	173	957	191.4
Distributed	84	99	88	88	104	463	92.6	110	137	120	127	145	639	127.8
Keep growing	97	101	95	83	95	470	94.0	138	147	136	119	130	670	134.0
1 inch germination	76	94	84	99	72	425	85.0	104	133	123	136	107	603	120.6
No irrigation	89	78	97	98	92	454	90.8	128	117	140	133	132	650	130.0

Irrigated in 1922 at	Cleaned grain yield in grams Series						Straw yield in grams Series					
	A	B	C	D	E	Average	A	B	C	D	E	Average
Germination	132	173	148	167	131	150.2	135	208	183	220	156	180.4
Tillering	221	104	124	192	175	163.2	361	196	148	247	205	231.4
Jointing	111	195	129	184	198	163.4	153	262	182	186	250	206.6
Heading	190	221	193	198	209	202.2	313	280	249	245	290	275.4
Blossoming	188	249	192	206	196	206.2	375	282	221	228	266	274.4
Filling	221	228	217	222	221	221.8	327	299	247	273	267	282.6
Distributed	177	178	166	214	222	191.6	225	303	216	240	275	251.8
No irrigation	210	199	194	172	178	190.6	280	267	225	395	247	282.8
1 inch germination	184	211	133	181	194	180.6	204	265	168	232	248	223.4
Keep growing	228	226	192	180	200	205.2	312	277	207	220	265	256.2

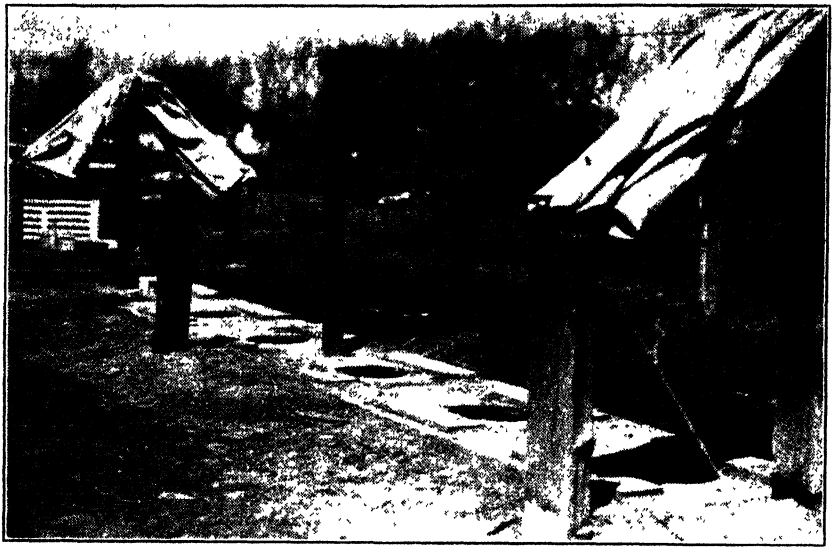


FIG. 7.—Potometer used in critical period experiment.

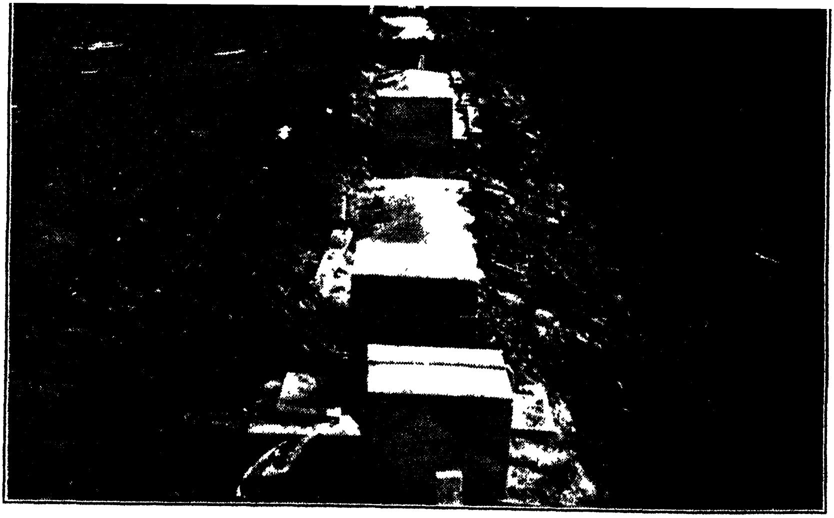


FIG. 8.—Potometers May 22, 1922, showing the heavy roofing paper used to cover the potometers and the boxes which protected the soil thermographs.

stratum in which it naturally occurred. The same man tamped each series of six potometers so that all the soils in one series would be as nearly uniform as possible. The trench around the outer containers was filled with soil at the same time the inner containers were filled. The inner container was set on blocks so that it protruded 1 inch above the outer container. Over the outer container and fitting the rim of the inner container was placed a wooden cover extending the length of the series. This cover was set on 2 by 4 boards buried in the ground. The rim of the inner container was sealed to the edge of the opening in the board cover with felt which had been dipped in "gas tar." This formed an airtight joint. The cracks between the boards were calked with cloth, thus making a continuous dead-air space around the inner container. The potometer series were covered with canvas in the same way as the field series. The general arrangement is shown in Fig. 7.

In 1921, the potometers were filled in the spring and planted several days later. Table 13 shows the amount of water applied to the potometers in 1921.

TABLE 13.—*Showing amount of water applied to the different potometers in 1921.*

Series F	Potometer 1	No irrigation
	Potometer 2	6 inches at seeding
	Potometer 3	1 inch at seeding and 5 inches at tillering
	Potometer 4	1 inch at seeding and 5 inches at jointing
	Potometer 5	1 inch at seeding and 5 inches at heading
	Potometer 6	1 inch at seeing and 5 inches at blossoming
Series G	Potometer 1	No irrigation
	Potometer 2	5 inches at tillering
	Potometer 3	5 inches at jointing
	Potometer 4	5 inches at heading
	Potometer 5	5 inches at blossoming
	Potometer 6	5 inches at filling

The soil for Series G was removed after Series F had been covered and in the interval a heavy rain had fallen. Potometer 1 Series G received no water while potometers 2 to 6, inclusive, received 0.5 inch before the tillering stage and 5 inches as shown in the table. In the fall after harvest the entire potometer series was covered with heavy tar paper, as shown in Fig. 8, to prevent moisture from reaching the potometers in the winter. These were uncovered in April and water was applied as follows in 1922. Potometers F1 and G6 received 7 inches at "germination," all other potometers receiving 1 inch at this time. Potometers F3 and G5 received 6 inches at "tillering;" potometers F4 and G4, 6 inches at "jointing;" and potometers F5 and G2, 6 inches at "blossoming."

The entire potometer series was taken up in the fall of 1922 and refilled and set up. The same care was taken in filling the potometers as in the experiment of 1921. The potometers were covered with heavy roofing paper and left covered until April, 1923, when they were planted to wheat. The arrangement, time of irrigation, and amounts of water applied are shown in Table 14.

TABLE 14.—*Showing the time and amount of irrigation and location of plats in the potometer experiment in 1923.*

When irrigated	Series	Potometer	Amount of water applied, inches	Total amount of water applied, inches
Germination....	H	2 and 7	6	6
Tillering.......	H	3 and 8	4[a]	6
Jointing.......	H	4 and 9	4[a]	6
Heading	H	5 and 10	4[a]	6
Blossoming. ...	H	6 and 11	4[a]	6
Filling	H	12	4[a]	6

[a] Each potometer received a 2-inch irrigation at germination.

The yields obtained from the several potometers in each of the three years are shown in Table 15.

The yield on the potometers never checked with the field experiments. The two years when the conditions were comparable, 1921 and 1923, show the yield of grain to be as follows: "Germination," "tillering," "jointing," "heading," and "blossoming." In 1922, the results were so inconsistent that they were not considered. However, the 1922 data indicate that if comparable results are to be expected the soil moisture content must be uniform at the beginning of the test. One reason for the contradictory results in the potometers is that the number of plants which mature varies more in the potometers than in the field plats.

GENERAL DISCUSSION

The influence of applying water to wheat at different periods is shown in the yield of grain and straw, the bushel weight, and the weight per 1,000 kernels.

On protected field plats when water was applied to Marquis wheat in six 1-inch irrigations at selected intervals distributed over the growing period there was an increased yield of grain and straw over all the other treatments. The highest yields of grain from a single irrigation were obtained at the jointing and heading stages. These results agree with those of several other workers. (See references to work of Von Seelhorst (14, 15), Harris and Pittman (6, 7, 8), and to statement by Smith (16) in "Review of Literature.")

Contrary to the findings of Widtsoe (20) at the Utah Station, the results obtained under controlled conditions at the Colorado Experi-

TABLE 15.—*Giving the yields and number of plants per potometer when water was applied at different periods.*

	1921					1922				
	Number of plants		Yield of grain in grams			Number of plants		Yield of grain in grams		
	F	G	F	G	Average	F	G	F	G	Average
Germination.......	26	23	15.5	5.4	10.5	27	29	10.0	16.0	13.0
Tillering...........	27	16	13.8	3.4	8.6	29	21	8.5	16.75	13.6
Jointing...........	—	—	5.1	5.0	5.0	27	28	18.0	9.0	13.5
Heading...........	—	19	8.6	3.0	5.8	31	24	4.0	5.4	4.7
Blossoming........	28	11	3.6	1.8	2.7	22	30	0.36	13.7	7.0
Filling............	—	3	—	0.21	0.21	—	—	—	—	—
			1923							
Germination.......	30	29	14.2	11.9	13.0					
Tillering...........	27	33	8.2	8.6	8.4					
Jointing...........	27	30	8.1	6.9	7.5					
Heading...........	25	23	5.5	7.5	6.5					
Blossoming........	27	21	5.9	5.4	5.7					
Filling............	—	20	—	12.5	Discard					

ment Station show that where 6 inches of water were applied at the "blossoming" stage or at the "filling" stage the yield of grain and straw combined was considerably less than for the four earlier irrigations.

The straw yield was also affected by the application of irrigation water. The earlier irrigations increased the yield of straw to a greater extent than did the later irrigations.

The difference in yield of straw between the plats receiving an irrigation at "germination," "tillering," or "jointing" was very small. The yield of straw with the three later irrigations decreased in the following order: "Heading," "blossoming," and "filling." Where the irrigation water was applied in small quantities distributed through the growing period the straw yield was very high.

The quality of grain as indicated by the bushel weight was also affected. The plats receiving water at "germination," "tillering" and "jointing" were light in weight per measured bushel. The heaviest grain was found in the plat receiving an irrigation at "blossoming." All of the later irrigated plats had heavier bushel weights than the earlier irrigated plats.

The weight per 1,000 kernels showd the variation in the weight of the thrashed grain from the different treatments. The grain from the plats receiving an irrigation at "germination," while weighing heavier per bushel than the grain from either the "tillering" or "germination" plats, weighed less per 1,000 kernels. The kernels were very badly shriveled. The grain from the plats irrigated at "tillering" and "jointing" weighed the same per measured bushel but differed in the weight per 1,000 kernels. The grain from the plat irrigated at "tillering" was more shriveled than that from the plat irrigated at "jointing." The grain from the latter plat was poorly filled but not shriveled.

There was a difference in the bushel weight of the plats irrigated at jointing and filling but the weight per 1,000 kernels differed very slightly. This was due to the difference in the type of kernels produced. Kernels from the plats irrigated at "jointing" were long and poorly filled, while the kernels from the plats irrigated at "filling" were small, short, and very plump.

The soil moisture condition at the end of the season indicated that a large percentage of the water applied after the heading stage was not used by the plant. This was further emphasized when the yields of square yards harvested from a bulk crop, grown on the field occupied by the critical period plats the previous year, were compared. The yields indicate that the moisture left in the soil by late irrigations affects the yield of the following crops. This agrees with the observations of Cole and Mathews (3) who found that the quantity of stored water influences the yield of spring wheat.

While many workers get results in pots which agree with field trials, it has been impossible thus far, to obtain results in potometers in agreement with these field trials.

SUMMARY

The time of applying irrigation water is an important factor in spring wheat production. Water applied at "jointing" increases the yield of straw and grain but not the quality of the grain as indicated by bushel weight and weight per 1,000 kernels.

When water is applied at "heading" slightly lower yields of grain and straw are obtained than when water is applied at "jointing." But the quality of grain is materially improved as indicated by bushel weight and weight per 1,000 kernels.

Irrigation as late as "blossoming" and "filling" has very little effect on yields of grain or straw, but has a marked effect on grain quality as indicated by weight per measured bushel.

Late irrigations at "heading," "blossoming," and "filling" have a residual effect on the following crop.

Early irrigations at "germination" and "tillering" increase the straw yield to a greater extent than the grain yield but produce a grain of poor quality.

Irrigations of small amounts (1 inch) distributed through the growing season give the best results but are impractical.

Soil moisture experiments carried out in potometers did not agree with similar experiments carried out under field conditions.

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CURING ALFALFA HAY[1]

T. A. KIESSELBACH AND ARTHUR ANDERSON[2]

Aside from texture and purity, the qualities which go to make up a good grade of alfalfa hay depend largely upon the curing operations. The practices of a successful curing system are planned in most regions to facilitate rapid drying of the forage, without undue loss of leaves. This shortens the interval between cutting and storage and thereby reduces the likelihood of rain damage.

Hay is cured in the field, either in the swath, windrow, or cock, or by some combination of these methods. It has been the purpose of these investigations, extending from 1921 to 1926, to establish the effectiveness of the various systems and also to determine the extent to which the leaves, through normal transpiration processes, may function in withdrawing moisture from the cut stems.

HISTORICAL

The literature contains very few comparative data pertaining to hay-curing methods. Of the many recommendations found, however, the majority favor either windrowing or cocking immediately, or very soon after cutting. The advocates of such practice commonly state that curing under these conditions is more rapid than prolonged swath curing, due to the more effective pumping action of the leaves in drying out the stems. Piper, *et al* (2),[3] question this and state that "There is serious doubt as to the accuracy of the theory that the leaves of the cut plants act as pumps. Nevertheless, the secret of making good bright, green hay is to reduce the water content in the plants from an average of about 70% to about 15% and to do this fairly rapidly and without allowing any of the leaves to become brittle dry."

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[2] Agronomists.

Vinall and McKee (3), working with sorghum, found that curing in the swath during the first four hours after cutting took place more rapidly than curing in the windrow.

Willard (4) concludes from laboratory tests that "Experiments to determine whether the leaves of plants draw water from the stems in the process of curing into hay indicate that this occurs with some plants and not with others. Alfalfa stems dried at the same rate whether the leaves were attached or not."

Westover (5) also concludes from a series of laboratory tests that "Alfalfa in the quantities here used cures at least as rapidly with leaves removed as with them attached."

EXPERIMENTAL[4]

RELATION OF CURING METHOD TO CURING RATE

A number of field curing tests have been made during the period of 1921 to 1926, contrasting the effectiveness of various methods. Although there was some interference by rain, two tests each in 1922, 1924, and 1926 were carried to successful completion, and their results are summarized herewith.

During the first two years, fortieth acre plats in a uniform alfalfa meadow were cured in duplicate by nine distinct systems. The first three methods consisted of curing the forage throughout in either the swath, windrow, or cock. In the fourth, fifth, and sixth systems partial swath curing to the three respective stages, approximating (a) beginning to wilt, (b) well wilted, and (c) two-thirds cured, preceded windrowing, in which condition curing was finished. The seventh, eighth, and ninth systems were identical with the preceding three, except cocking was substituted for windrowing. In all

[3] Reference by number is to "Literature Cited," p. 126.

[4] The investigations pertaining to the curing of alfalfa hay from 1921 to 1925 are published in detail in Nebr. Agr. Exp. Sta. Res. Bul. 36, and are herewiht abstracted in part. In addition further field curing tests conducted in 1926 and sorghum and Sudan grass curing tests conducted in 1924 are reported.

cases, the windrows and cocks were of average size and normal field conditions were maintained.

The tests of 1922 and 1924 were conducted in essentially the same manner and are summarized in Table 1 to show the number of hours required to reduce the forage as cured under these various systems to 30% moisture content. Thirty per cent is regarded as the extreme upper limit of moisture content at which alfalfa hay may be safely stacked. The moisture content of 102 samples, taken when the forage was regarded sufficiently cured to stack, averaged 23%.

By determining the moisture content of representative samples taken from each plat at 7 and 10 a. m. and 1 and 4 p. m. daily, it was possible to determine rather closely the time at which the moisture content was reduced to the point in question.

As an average of the four curing tests, it required 27, 65, and 102 hours, respectively, for the continuous swath, windrow, and cock curing to reduce the forage to 30% moisture content. Where swath curing to the three stages, "beginning to wilt," "well wilted," and "two-thirds cured" preceded windrowing, a total of 50, 44, and 29 hours were required, respectively. In the corresponding test in which cocking was substituted for windrowing, 53, 45, and 29 hours were required for the three different combinations. The relative rates of curing hay by these nine different systems are shown graphically for 1924 in Fig. 1.

Two simple tests were made in 1926, comparing the relative curing rates of alfalfa hay in the swath and in the windrow as made by a left-hand side-delivery rake. The results are shown in Figs. 2 and 3. In the first tests, begun on June 8, duplicate plats were cut at 9 a. m., at which time the alfalfa contained 67% moisture. Within nine hours after cutting the swath-cured hay had reached 30% moisture content, whereas the hay windrowed immediately after cutting still retained 43% moisture and did not reach 30% until 28 hours after harvesting.

In the second test, begun at 9 a. m., on June 17, a third system of curing was included. Hay left in the swath throughout again cured somewhat more rapidly than the hay windrowed immediately, reaching 30% moisture in nine hours, as compared with 28 hours. Windrowing, preceded by six hours of swath curing, checked the drying rate somewhat, but was more effective than the system of windrowing immediately after cutting.

These two tests do not substantiate the claim that hay raked into windrows by a side-delivery rake while still in a green condition loses water more rapidly as a result of such raking.

TABLE I.—*Number of hours required for hay curing in swath, windrow, and cock to reach 30% moisture content as determined by composite samples taken periodically.*[a]

Test beginning 10 a. m.	Curing throughout the test in			Partial swath curing preceding windrowing and cocking for[b]					
				3 to 6 hours		6 to 21 hours		24 to 27 hours	
	Swath	Windrow	Cock	Windrow	Cock	Windrow	Cock	Windrow	Cock
	Total number of hours from time of harvesting								
June 7, 1922	27	96	102	96	96	72	69	30	30
August 22, 1922	27	54	99	48	51	48	51	30	30
July 30, 1924	30	78	126	30	33	30	33	30	33
August 18, 1924	24	33	81	27	30	24	27	24	24
Average	27	65	102	50	53	44	45	29	29
	Number of hours from 7 a. m. to 7 p. m. during test								
June 7, 1922	15	48	54	48	48	36	33	18	18
August 22, 1922	15	30	51	24	27	24	27	18	18
July 30, 1924	18	42	66	18	21	18	21	18	21
August 18, 1924	12	21	45	15	18	12	15	12	12
Average	15	35	54	26	29	23	24	17	17

[a] Hay with 30 to 32% moisture content at 4 p. m. was considered as having 30% or less by 7 p. m.

[b] These periods represent the approximate stages: Beginning to wilt, well wilted, and about two-thirds cured.

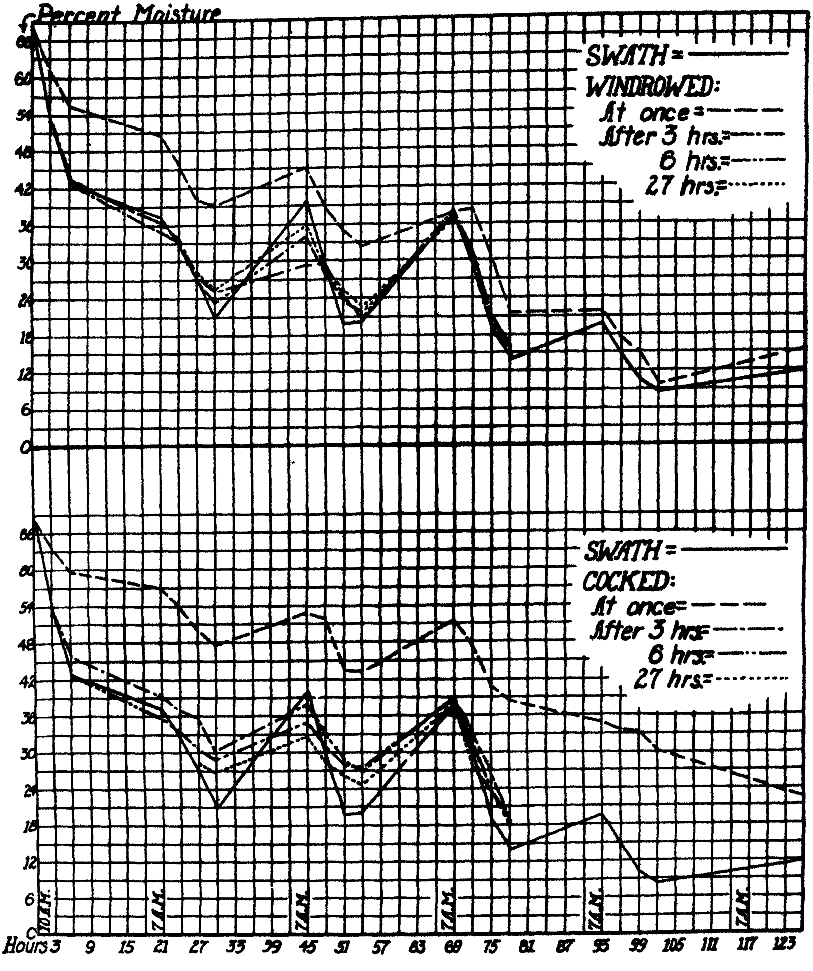

FIG. 1.—Comparative curing of alfalfa hay in the swath, windrow, and cock as determined from composite samples of forage taken daily at 7 and 10 a.m. and 1 and 4 p. m. Average of tests beginning July 30 and Aug. 18, 1924.

It is evident from all of these tests that windrowing ro cocking relatively green forage will materially prolong the curing period, and that the time required to reduce hay to a field-cured or air-dry condition is shortened as the period of swath curing is extended.

FUNCTION OF LEAVES IN CURING HAY

This phase of the problem has been approached from two angles: (A) If the natural transpiratory activity of the leaves may be employed to accelerate curing by "pumping" water from the stems,

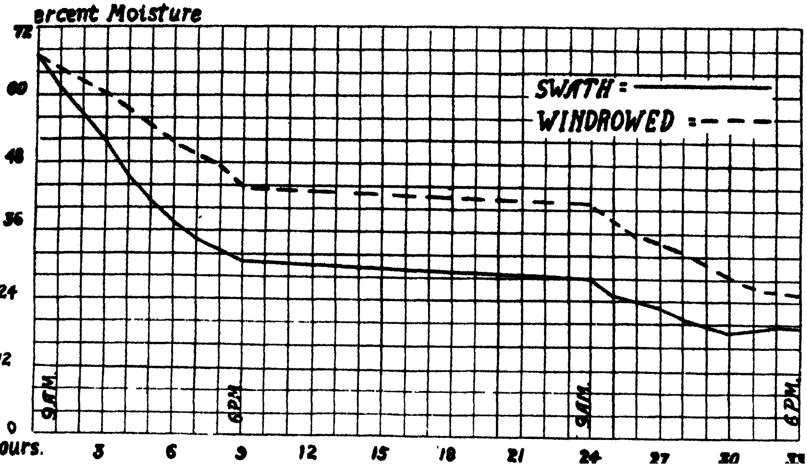

FIG. 2.—Comparative curing of alfalfa hay in the swath and windrow (windrowed by a left-hand side-delivery rake) as determined from composite samples of forage taken at hourly intervals from 9 a. m. to 6 p. m. June 8 and 9, 1926.

then the rate might be expected to be lowered in experimental tests in which the leaves have been severed from the stems. The water loss by "bleeding" from such stems seems negligible, as it was not observed in these tests. Accordingly, comparative curing rates have been determined both in the field and in the laboratory for forage

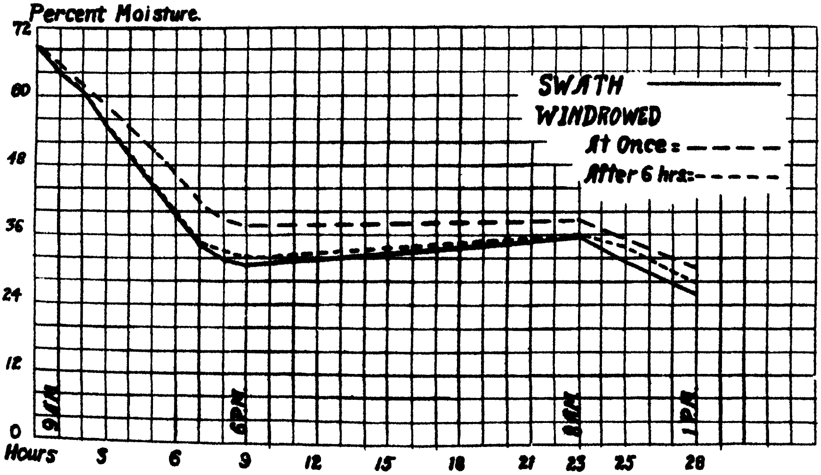

FIG. 3.—Comparative curing of alfalfa hay in the swath and windrow (windrowed by a left-hand side-delivery rake) as determined from composite samples of forage taken at hourly intervals from 9 a.m. to 6 p.m. during the first day and at 8 and 10 a. m. and 1 p. m. on the second day. June 17 and 18, 1926.

having the leaves intact and detached. (B) If raking or cocking forage while yet fairly green permits transpiration to continue to any great extent in the curing process, as has been frequently stated, then hay put up by such practice should cure more rapidly than if left to cure in the swath. The foregoing tests have indicated that such is not the case.

FIELD TESTS

These determinations were made in connection with the 1922 and 1924 curing experiments previously reported. A series of representative samples of forage with leaves attached and detached, respectively, were prepared at the beginning of the period and retained thereafter in small bags made of thin, white, coarsely woven material known as tarlatan. This enclosure affected the normal curing rate but little, as evidenced by great similarity with the results from the composite samples taken periodically. The detached leaves were mixed with the stems from which they had been stripped. Except when removed for weighing these samples were kept under the conditions which they represented, namely in the swath, windrow, or cock. Moisture losses from these samples were determined by weighing at 7 and 10 a. m. and at 1 and 4 p. m. daily.

A study of the rate of curing of samples having their leaves intact and detached, respectively, indicates that the functioning of the leaves is under no conditions significantly instrumental in the withdrawal of moisture from the stems of cut forage. Of the 487 comparisons in which moisture determinations were made for both kinds of samples, it was found that their moisture contents differed not more than 1% 253 times, or in 52% of the comparisons. In the remaining tests, or those differing more than 1%, each type of sample contained the most moisture in an equal number of cases. The parallel curing rates of the forage with leaves intact and detached, averaged for the two 1924 tests, are shown graphically in Fig. 4.

CORROBORATIVE TESTS WITH SORGHUM AND SUDAN GRASS

A similar test to determine the function of leaves in pumping water from the stems as a curing process was made with Black Amber sorghum and Sudan grass during the fall of 1924. Representative samples of forage having the leaves intact and detached, respectively, were cured in the swath, windrow, and cock, as has been described for alfalfa. The results as averaged for these three systems are plotted for each crop in Fig. 5. The parallel curing rates of both kinds of samples indicate that transpiration from the leaves does not aid materially in the curing process.

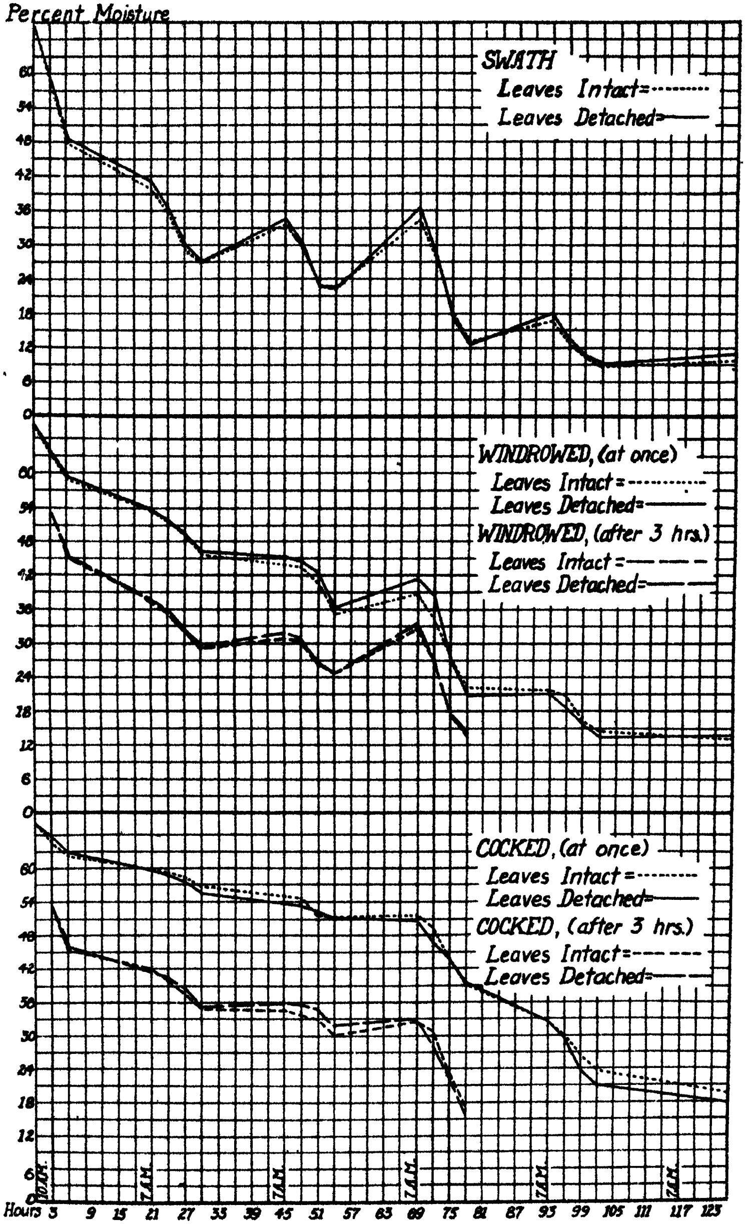

FIG. 4.—Function of leaves in the field curing of alfalfa hay. Comparative rates of curing forage with leaves intact and detached in the swath, windrow, and cock, respectively, as determined from weighings made at 7 and 10 a. m. and 1 and 4 p. m., daily. Average of tests beginning July 30 and Aug. 18, 1924.

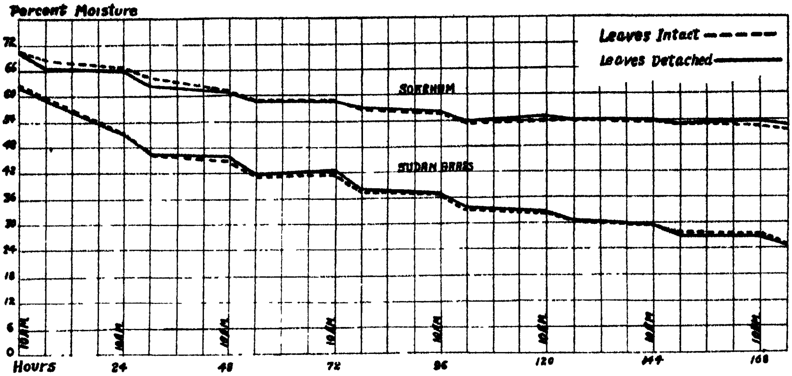

FIG. 5.—Function of leaves in the field curing of sorghum and Sudan grass hay. Comparative rates of curing forage with leaves intact and detached, respectively, as determined from weighings made at 10 a. m. and 4 p. m., daily. Sept. 3 to 10, 1924.

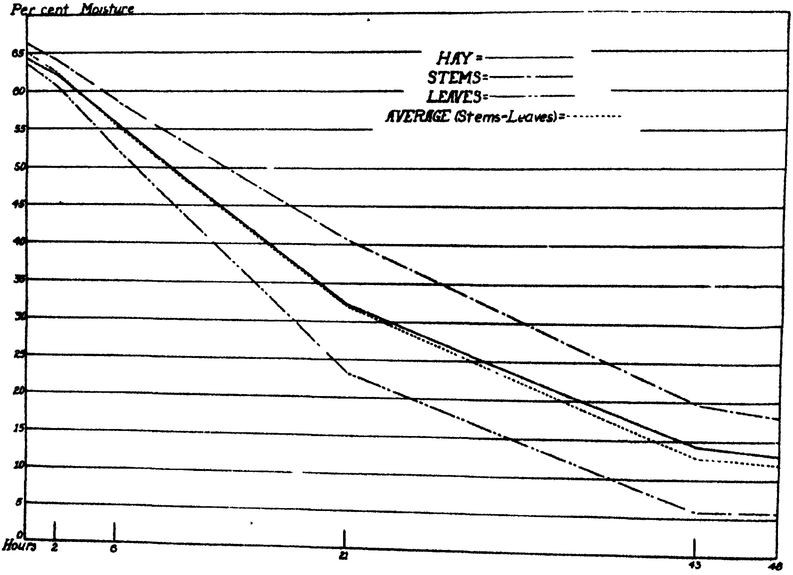

FIG. 6.—Comparative drying of alfalfa hay, leaves, and stems under laboratory conditions. June 6, 7, and 8, 1925.

LABORATORY TESTS

A number of simple tests were conducted in the laboratory wherein the loss of moisture from samples of alfalfa with leaves intact was compared with the loss from alfalfa from which the leaves had been stripped. These samples were scattered thinly on sheets of paper and placed in a well-exposed position for curing, but not in direct sunlight. The results of a typical test, made in 1925, are shown graphically in Fig. 6. The normal hay dried somewhat faster than the stems alone, but when the curing rates of the stems and leaves are averaged, the rate is almost identical with that of whole hay. As in the field tests, these data indicate that leaf activity is not an important factor in the curing of alfalfa.

EFFECT OF CURING METHODS UPON QUALITY OF HAY

From the mere standpoint of speed and avoidance of rain damage, curing throughout in the swath followed by storage as soon as sufficiently dry would appear to be advantageous. Such practice, however, is not to be recommended when maximum quality and yield are considered. Prolonged swath curing results in undue shattering of leaves. Partial swath curing, however, may be practiced without material loss in quality. These facts are developed in Table 2 which summarizes the percentage loss in weight suffered by alfalfa when cured under the nine different systems in 1924. Alfalfa left in the swath until field cured lost nearly 10% in weight through the shattering of leaves. When cured entirely in the windrow or in combination with three to six hours initial swath curing, only 1 to 2% loss resulted. This combination of partial swath curing followed by windrowing would seem to be the best farm practice in this region. The duration

TABLE 2.—*The amount of hay (percentage dry matter) recovered from the various curing methods as an average of the curing tests beginning July 30 and August 18, 1924.*

Method of curing	30% moisture content reached in[a]	Hay (dry matter) recovered when Field cured	Test ended	All plats averaged
	Hours	%	%	%
Swath	27	90.7	81.5	86.1
Windrow, throughout	56	99.9	95.3	97.6
Windrow, preceded by 3 hours swatch curing	29	97.8	98.3	98.1
Windrow, preceded by 6 hours swath curing.	27	99.1	94.4	96.8
Windrow, preceded by 24 to 27 hours swath curing	27	94.5	91.4	93.0
Average	35	97.8	94.9	96.4
Cock, throughout	104	96.3	96.3	96.3
Cock, preceded by 3 hours swath curing	32	98.4	98.0	98.2
Cock, preceded by 6 hours swath curing	30	96.3	96.5	96.4
Cock, preceded by 24 to 37 hours swath curing	29	95.0	91.5	93.3
Average	49	96.5	95.6	96.1

[a] Number of hours required for hay to reach 30% moisture content. From Table 1.

of the swath curing will depend upon local conditions. Prompt storage when cured is desirable to avoid unnecessary shattering of leaves, rain damage, or bleaching. The amount of bleaching which results from judicious partial swath curing would not appear to lower the feeding value of the hay.

SUMMARY

Windrowing and cocking relatively green hay materially extended the curing period as compared with swath curing. Prolonged swath curing resulted in undue loss of leaves and bleaching. Judicious, partial swath curing to hasten the rate of drying, followed by windrowing and by prompt storage when cured would seem to be the best farm practice for this region.

The normal transpiratory function of the leaves in cut alfalfa is a negligible factor in the curing process.

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A METHOD FOR CONTROLLING POLLINATION OF SUGAR BEETS[1]

George Stewart and D. C. Tingey[2]

A few years ago there was considerable effort in the western United States to improve by breeding the yield or the quality, or both, of sugar beets. Usually, ordinary chemical mass-selection methods were employed, but there were also some efforts to control pollination. In the end these attempts were abandoned, some for one reason and some for another. It seems probable that inability to make enough progress to warrant the continuation of sugar-beet breeding was due, at least in part, to lack of success in controlling pollination.

Bags of cotton gauze placed over the entire plant did not appear to prevent cross pollination. Some entomologists attributed this to thrips getting through the bags or below them. At any rate no control resulted. Then closely woven silk was tried but unsuccessfully. Some investigators thought that bagging the entire plant weakened it; others thought that the enclosed air became too humid for seed setting. A few tried bagging individual branches but without success.

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[1] Contribution from the Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Received for publication November 15, 1926.

[2] Agronomist and Assistant Agronomist, respectively.

A few workers believed that they could successfully control pollination by distance isolation of plants. Great labor and expense were involved in this method and chance crosses with mangels, with garden beets, or with escaped plants caused more or less trouble.

In 1925, the writers' attention was called to reports of success in bagging at Svalof, Sweden. In 1926, this method was tried at the Utah Agricultural Experiment Station.

In the fall of 1925, about 300 beets were gathered and tested for sugar content. Of these, about half were discarded because of low test. The remaining beets were stored in a good root cellar. A few rotted in storage. The remainder were set out in the spring of 1926. A few did not grow after being set out, due in part to unusually dry weather. Altogether, 100 beets grew, and the branches of about 75 of these were bagged with 2-pound paper grocery bags. From five to ten bags were placed on each plant and tied tightly with heavy cotton twine. In some cases single small branches only were enclosed; in others a whole cluster was enclosed, so many small branches that the bags were nearly filled.

At harvest some bags had been broken and some had loosened. These were discarded and only those saved that had remained tied so tightly as to prevent the entrance of thrips. All the bags from one

TABLE 1.—*Number of self-pollinated seeds obtained from various sugar-beet plants with 5 to 10 two-pound paper bags on each plant.*

Plant No.	No. of seeds	Plant No.	No. of seeds	Plant No.	No. of seeds	Plant No.	No. of seeds
14	124	89	66	173	87	226	2
23	137	90	2	175	167	233	25
24	125	91	66	180	224	236	35
35	1	97	48	181	366	237	19
36	600	101	143	182	80	238	38
37	550	102	26	185	300	241	4
44	2	105	400	189	1	243	2
51	110	107	8	190	24	246	18
56	57	113	15	204	2	248	13
59	191	115	1	206	50	249	11
60	49	116	176	210	19	253	6(?)
61	13	134	4	212	137		
63	48	149	29	215	500		
69	237	158	286	216	600		
71	3	160	325	222	8		
74	20	164	500	225	116		

plant were placed together and the plant material allowed to dry. Later the seed was gathered and counted, with the results shown in Table 1.

As a whole it may be said that the sugar-beet self-fertilized rather freely by this method under 1926 conditions at Logan. Some plants appear to be much more highly self-fertile than others. This is of course only one year's data, but the behavior of sugar-beets in this one season is not materially different from the usual behavior of several other crops.

Most of the bags in which several branches were enclosed yielded no seed or at least only a few. Many of the bags which enclosed single branches and thereby allowed plenty of room have 20 to 30% as many seeds as similar branches not bagged. Most of the bags, however, yielded only a few seeds, i. e., 1 to 5% as many as exposed branches.

Recently, it has been suggested to the writers that wrapping a strip of cotton around the stem before tying the bag might still further insure the tying. This has not yet been tried.

ENTOMOLOGICAL RESEARCH ON THE EUROPEAN CORN BORER IN OHIO[1]

L. L. Huber and C. R. Neiswander[2]

INTRODUCTION

That the European corn borer problem is the most important entomological project and one of the great agricultural problems with which Ohio and neighboring states are dealing at the present time scarcely needs to be discussed. While the problem is essentially an entomological one, it is of such far reaching economic consequences that it has demanded and is now receiving the attention of men engaged in almost every profession. It is only fair to state, however, that of all the agencies now actively assisting in its solution the agronomists probably constitute the most important group. It is, therefore, a privilege and a pleasure to discuss the status of corn borer research with the members of the American Society of Agronomy.

This discussion of the subject will be confined to the biology and ecology of the insect, with special emphasis on the possibilities of control by parasites, agronomical practices, and mechanical measures. This paper will not deal particularly with the *modus operandi* of any method of control nor attempt to point out the futility or the merit of any control measure. It will be the aim rather to present the information which is now available in order to make it possible for others to better evaluate not only the measures which are now in operation but those which are yet to be devised.

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[1] Paper read at the meeting of the Society held in Washington, D. C., November 18, 1926. Contribution from the Department of Entomology, Ohio Agricultural Experiment Station, Wooster, O.

[2] Associate and Assistant Entomologist, respectively.

By way of introduction, also, it may be well to indicate briefly the increase in infestation in Ohio during the past four seasons. In the Bono, Ohio, area the maximum infestation in 1923 was 17%, in 1924 it was 40%, in 1925 it was 65%, and this year (1926) it was 100%. What is still more significant, the average maximum borer population per infested stalk was less than 1 in 1923; slightly more than 1 in 1924; about 2 in 1925; and 10 in 1926. This year there is the first appreciable commercial damage. The increase in borer population this season was 500% despite the fact that there was without question a good practical clean up.

CONTROL OF CORN BORER BY PARASITES

In this connection it should be remembered that control by parasites is an experiment. There are few reasons to feel either particularly optimistic or particularly pessimistic in regard to the final outcome. On the one hand, it must be kept in mind that parasites do not control the corn borer in Europe, yet on the other hand there are those who insist that those same parasites brought here without their enemies may in time become very valuable indeed. Control by parasites has seldom been spectacular but it has often been of tremendous value. The extreme damage caused by the corn borer in North America and experience with the control of other insects by parasites warrant the experiment.

CONTROL BY AGRICULTURAL PRACTICES

This leads to a consideration of the biology of the insect with special reference to the possible agricultural adaptations that may be necessary. Research prior to the beginning of investigations in Ohio in 1923 seemed to indicate the two following conclusions: First, that it was not probable that immunity would be found in any variety; and second, that corn planted late was not damaged to the same extent as corn planted early. These conclusions, especially the latter, provided the basis for the agronomical phase of the attack of the problem. Studies of the insect, therefore, have revolved quite largely about not only a difference in the planting date, but also about a difference in the varieties planted. It was the intention to establish, if possible, not only a "corn borer free date" but also to determine what variety was most suitable for such planting, and, furthermore, if no ordinary variety proved adaptable, then an attempt was to be made to develop a suitable variety.

The general relationship existing between degree of infestation and time of planting has been established quite definitely. This relationship will be illustrated in connection with the following paper, hence need not be presented here. It is sufficient to say that, other factors being equal, there is a consistent and gradual decrease of infestation as the planting date is delayed. Some of the details of this apparent relationship and the evidence concerning the underlying causes may now be discussed. The first interest lies in the behavior of the moths in reference to the special planting dates. The corn borer moth is a night flier. Repeated night observations have shown conclusively that the early planted corn is more attractive to the moths than late planted corn. During the time of maximum flight, about the first week of July, great numbers of moths can be seen flying over and in the early planted corn; whereas over late planted corn, separated only by the distance of a few feet from the earlier plantings, only occasional moths could be observed. However, as the season progressed the late corn evidently became more attractive, for during the latter part of the moth flight a greater percentage of moths was observed in the late planted areas.

In view of the behavior of the moths it was not surprising to learn that the great bulk of the eggs was deposited on early planted corn. Furthermore, infestation data taken on experimental plats have always indicated a heavier stalk infestation and a greater borer population per stalk in early planted corn than in late planted corn.

The evidence is conclusive that the moths prefer early planted corn, that more eggs are deposited thereon, that more stalks are infested, and that there are more borers per infested stalk, consequently greater damage results

This conclusion leads to a consideration of two important questions. First, what would happen should there be two generations per year instead of one; and second, what would be the outcome should all corn be planted late, the moths thus concentrating upon it? At this time it is possible to say no more than that two generations per year would seriously complicate the agronomic program. As to the second question, it must be admitted that no field experiments in Ohio or elsewhere have been sufficiently extensive in acreage to permit conclusive statements as to just what would occur if all corn were planted late. Such opinions and tentative conclusions as are now held are based on numerous field observations and upon artificially controlled experiments. Evidence from these two sources indicates that even though all corn were planted late it would possibly suffer no greater damage than at the present time. Apparently the chemical and morphological character of the smaller corn plants is inimical to the physiology of the borer. The extent to which this conclusion is accepted is evidenced by the continuation of experimental work along agronomic lines.

FACTORS INFLUENCING THE BEHAVIOR OF CORN BORER MOTHS

The behavior of the corn borer with reference to corn planting dates has been discussed. The paper which follows will discuss varieties and their relation to corn borer attack. This leads to a consideration of the causative factors influencing behavior of the moths. The possibility that in some areas in Ohio there may be two generations per year instead of one makes it all the more imperative that it should be known why the adults show degrees of preference for corn planted at various dates and under various conditions and circumstances. Unless these underlying factors can be discovered and isolated it will be impossible to proceed in the most logical and intelligent manner. Consequently the project has now entered the period of fundamental research.

In accordance with the general plan of procedure the plant physiologists have begun in Ohio a careful study of the morphology and physiology of the corn plant. It is needless to say that it would be difficult, if not wholly impossible, to interpret the reactions of the corn borer without some knowledge of the physiology and chemistry of its food plant. The first problem along this line has been an attempt to find the possible stimulus that attracts the moths. While no particular attractant has been isolated, yet it is certain that whatever it may be that attracts the moths it is contained wholly or in part in distillates made from the corn. For example, in laboratory experiments when moths are free to choose between distillates from early or late corn, vigorous or weak corn, they select the distillates made from the early and the vigorous plants. Other reactions were noted, but details will not be given here. The point is that apparently certain odors from the early and sturdy plants attract the moths. It is within the realm of probability that without these odors the corn plant would perhaps be no more attractive to the moths than many other plants. If this probability be true, is there not an added reason to believe that even if all corn were planted late there would be little or no damage?

In addition to the physiological studies of the corn plant in connection with physiological studies of the insect attention is also being given to the morphological characters of the plants. Suffice it to say that certain morphological characters of the corn plant greatly affect the behavior of the insect.

MECHANICAL MEANS OF CONTROL

Experiences with certain insects have shown that in some instances such measures will afford relief, but in others they are of little or no avail. There are at least two important factors to consider in any attempt to control an insect by mechanical efforts. In the first place much will depend upon the efficiency of the measure employed, i. e., the reduction of the species in question must be such that those remaining will be so few in numbers that, other factors being equal, their progeny will cause no damage. In the second place, the efficiency of even an admittedly good mechanical measure may depend quite largely on the behavior of the insect in its relation to its environment, for it is a fact known to all that many animals as well as plants do better in certain habitats than in others. There is no reason to believe that the corn borer is an exception to this general rule. With these two factors in mind, namely, the nature of the control itself and the biology and ecology of the insect, the possibilities of mechanical control may be analyzed. In this connection there are two general points we wish to discuss, namely, (1) the actual distribution of the insect and (2) its ecological habitats.

Each year since 1923 Ohio entomologists have made a survey of the infested areas in the state in order to determine the actual distribution of the insect. Records for four years are now available. It may be of interest to know that in Ohio as well as elsewhere there are areas where the infestation has been consistently high and other areas where it has been consistently low. There is a narrow strip in the townships directly adjacent to Lake Erie which has a comparatively high degree of infestation as compared with the area farther back from the Lake. In northeastern Ohio this strip does not average more than 3 miles in width, but in the northwestern part of the state the area of high infestation is greatly extended. In one particular section of this general area, the infestation has been extraordinarily heavy. In fact, the first commercial damage in Ohio has occurred in this small area. In the area just west of Toledo the infestation has always been low. Even this year with commercial losses east of Toledo the infestation to the west is practically negligible. Actual distribution of the insect, therefore, indicates that for some reason the corn borer finds living conditions better suited to its economy in some areas than in others. This has been true not only in Ohio but in New England, New York, Canada, and elsewhere.

The second consideration is that of ecological habitats. When it was noted that the degree of infestation of the corn borer was apparently influenced by certain natural factors an explanation was sought. While the explanation has not been found as yet, still certain information has given not only an added insight into natural factors, but it has been possible to correlate it directly with the data already mentioned. At this time it is impossible to go into great detail concerning ecological habitats in reference to the corn borer. Suffice it to say that during the past season Dr. E. N. Transeau and Dr. H. T. Sampson of Ohio State University spent the summer with the Ohio entomologists for the specific purpose of aiding in an attempt to find an ecological index to the degree of infestation of the insect. This survey included Ohio and parts of Michigan, Indiana, Pennsylvania, New York, and Canada. The study indicated that the boundary lines of ecological habitats of certain forest types coincide with boundary lines of the areas of high and low infestation of the insect.

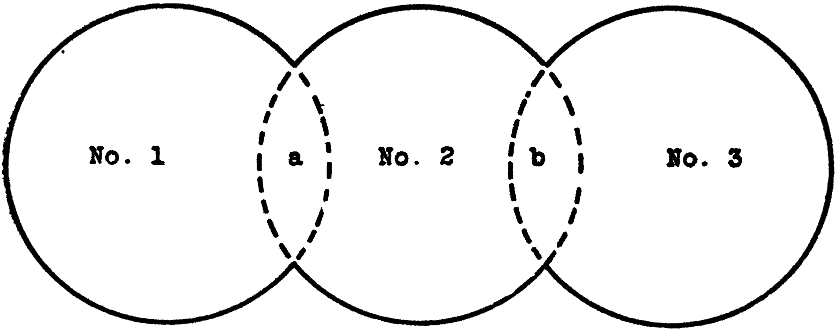
The explanation has not been found, but there are indications that the behavior of the insect and the distribution of the forest types are both greatly influenced by the same factors. According to Transeau, "The oak-hickory forest (when original) is generally found in drier areas, either because of dry climatic conditions, or because of over drainage or a combination of both. The beech-maple forest usually represents more moist conditions, both of atmosphere and soil. The swamp forest is typical of areas with a high soil water table and constantly humid conditions." Ecological information relative to the corn belt is a matter of more or less general knowledge. Basing judgment, therefore, on the past behavior of the insect and upon knowledge of the ecological habitats of the corn belt, it can perhaps be expected that although the corn borer will spread over the entire corn-producing area it will not be equally serious in all places. The results of the field studies as mentioned above, together with artificially controlled laboratory experiments, indicate that the corn borer flourishes best under conditions of high and constant humidity. However, it is realized that there are many factors to be taken into consideration before the future behavior of the corn borer can be definitely predicted. Since this is one the first major pests that has ever been studied over such an extensive area in this particular manner, the problem must be approached with an open mind.

It was stated at the outset that the merit of any control measure would not be discussed. However, in order to consider briefly one of the recently suggested methods for retarding the corn borer, digression is made from the main purpose of this discussion at this point. For the benefit of those unacquainted with this proposal it should be said that it has been suggested that Congress recognize the corn borer problem as a national one and appropriate funds to be used this coming spring in thoroughly cleaning up the entire infested area of the United States, exclusive of New England. The stated purpose of the proposed clean-up is to retard the corn borer. The ideas carried in the proposal are so bold and daring that the whole scheme has been the subject of much vigorous and earnest discussion.

In considering this proposal there are certain fundamental facts which must be kept constantly in mind. There are also at least three important groups vitally interested, namely, the economists, the entomologists, and the farmers. It is argued that if the clean-up be a national problem the additional costs of attemtping to hold the insect in check should be borne by Federal appropriation, the appropriation to be used in some form of reimbursement to the farmers within the infested area. It is the opinion of many that if this gigantic experiment is conducted the costs certainly should not be assessed against the farmers who bear the brunt of the fight. However, there are those who claim that any scheme which would directly or indirectly provide for the reimbursement of the farmer would strongly suggest class legislation. Those in favor of reimbursement answer that the present situation constitutes an emergency and reimbursement is, therefore, justifiable. It seems evident that the acceptance of the proposed experiment from an economic standpoint will depend quite largely upon the ability of its adherents to formulate a workable and satisfactory method of reimbursement.

However, regardless of any schemes of the immediate future it certainly is an obvious fact that ultimately the corn borer problem will become the farmer's problem, but the consuming public will pay the bill. Reimbursement cannot be other than a temporary measure designed as an aid to those within the infested area and as a form of insurance for those outside the infested area in that the borer would supposedly be retarded. There is this additional thought that when reimbursement is discontinued public officials will stand in grave danger of finding themselves in a very difficult position, in that they may be hampered not only because of the discontinuance of funds but also by an undeveloped educational program. It will be well in this formative period to remember that permanent practices are generally the result of educational efforts rather than mercenary or coercive measures.

However, the interests of the entomologists in the economic aspects of the proposal are secondary to the biological possibilities of the experiment. It has been noted perhaps that relative to this experiment the entomologists have been more or less noncommittal. They find themselves in a rather unfortunate position in that they may be misinterpreted if they say what they believe. While it is frankly admitted that not a great deal is known relative to this insect, still enough is known concerning its biology and the apparent possibilities of mechanical measures of control to cause entomologists to have some serious doubts as to the biological soundness of the experiment as proposed. Entomologists are compelled to say that if the past behavior of the corn borer is any criterion of its future behavior, the chances of retarding the insect to an appreciably greater extent than it has been retarded in the past by voluntary efforts are rather meager indeed. The proposition, as the entomologists see it from the biological viewpoint, resolves itself into a gambler's chance to accomplish a task which smacks of the impossible. But it may be that the stake is so important that officials are justified in casting discretion to the side and taking the chance. If the public accept the experiment, it must be accepted on this basis.



No. 1 - Optimum environment

No. 2 - Favorable environment

No. 3 - Unfavorable environment

a & b - Transition zones

FIG. 1

It is fully realized that the foregoing statements are likely to be misinterpreted, especially by those who have not had an opportunity to study the insect at first hand. The accompanying illustration (Fig. 1) should help explain the entomological viewpoint. There are drawn here three intersecting circles. In Circle No. 1 is included a corn-growing area which affords an optimum environment for the corn borer. In this area, other factors being equal, considerable trouble will always be had in controlling the insect. Mechanical means of control will help, but such means alone will not be sufficient to insure the continued production of corn. Circle No. 3 includes an area which will have but little difficulty with the borer. Climatic factors alone probably will keep the insect so reduced in numbers that commercial damage will be unusual. Within Circle No. 2, however, is an area which is potentially dangerous. In this area there exists a delicate balance between the economy of the species and climatic factors.

The areas included jointly within Circles Nos. 1 and 2 and Circles Nos. 2 and 3 constitute transition zones in which the behavior of the borer may vary from year to year according to local weather conditions. For example, while the area within Circle No. 1 will always be heavily infested, there will be times when the weather will be so unfavorable that mechanical measures alone would hold it under control. However, inasmuch as the critical months in the life history of the species come after the clean-up a chance on control by the weather can never be taken. On the other hand, a part of the area in Circle No. 2, with favorable weather conditions, may suffer great losses if dependence is put entirely on mechanical measures. The areas common between Circles Nos. 2 and 3 are explained in a similar manner.

CONCLUSIONS

An attempt has been made to outline the general biological basis for the control measures now in operation as well as those which are yet to be devised. While it must seem obvious that the corn borer problem will be solved by a combination of measures, it is also evident that whatever these methods may be each will have its limitations. And unless proper cognizance of the biology of the insect is taken into consideration, how can the significance of the limitations and the importance of the control measure as a whole be properly evaluated? It is, therefore, extremely important that the work of all agencies be properly synchronized. It is important too that great caution be exercised lest in the frenzy to obtain results or in the mad scramble for publicity, whichever the case may be, the value of any particular proposal is not overemphasized or underestimated. It is to be remembered that before a policy of control is formulated it should be reasonably certain that the policy is in accord with scientific information. Every proposed method of control of whatever nature it may be should be weighed in the balance of scientific evidence and if it be not found in accord with fundamental truths let it be accepted only with reservations or entirely rejected; but if it be in accord let it be accepted and if practical put into operation. It is to be remembered that every allied phase of research is dependent upon the knowledge of the biology of the insect. It is to be kept in mind that all the control measures of the present and future must of necessity be based on the truth as established by research. Conferences, regulations, legislation, resolutions, publicity, and the like are all of value, but let it be distinctly and clearly understood that the prime need of the present is research. The burden of the problem, as it is now understood, lies with all the agencies interested in agriculture, but more particularly with the agronomists, the engineers, and the entomologists.

AGRONOMIC RESEARCH ON THE EUROPEAN CORN BORER IN OHIO[1]

ROBT. M. SALTER AND L. E. THATCHER[2]

Entomologists who are in contact with the corn borer problem appear to be agreed upon one point. By none of the present known methods of control will it be possible to exterminate the corn borer. The voluntary or enforced adoption of mechanical methods of control plus what may be accomplished through the introduction of parasites may delay the day of serious commercial damage, possibly for an indefinite period These same measures may slow up the rate of spread of the insect into non-infested territory, although this seems less probable. In any event, for many years to come, there will probably be seasons when in some regions the corn borer will be an important factor in increasing the cost of corn production. In other words, the corn borer is here to stay, and it will be the agronomist's particular job to do what he can to make it possible for the farmer to grow corn profitably in spite of corn borer infestation, more or less severe, depending upon the season and the effectiveness of control methods.

The suggestion has been made that if the farmer could be induced to reduce his corn acreage voluntarily the problem of control might be greatly simplified. This suggestion will meet with little favor in the larger corn-producing states where the corn borer problem is apt to be most serious. Any policy which requires the farmer to reorganize his entire cropping system is fraught with danger. While the replacement of corn by alfalfa, sugar beets, tobacco, or by any other crop may appear economically sound in some sections at the present time, there is little assurance that the wholesale adoption of such substitute crops would not result in their over production with serious economic loss to the farmer. The higher cost of growing corn under corn borer conditions, incident both to damage by the insect and to the expense of control measures, will in itself tend to force marginal producers to give up corn in favor of other crops. This process is to be preferred to any program of propaganda for voluntary reduction in acreage, which, like any other educational movement, would elicit least response among those farmers constituting the marginal group.

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[1] Paper read at the meeting of the Society held in Washington, D. C., November 18, 1926. Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, O.

[2] Agronomist and Associate Agronomist, respectively.

Agronomists in Ohio have been cooperating in a general program of corn borer research since 1923. Previous to that time the entomologists had secured data indicating that the time of planting corn might be a large factor in determining the percentage of infestation and that other cultural practices, such as rate of planting, might be important. The question had also been raised as to whether there existed any differences between corn varieties in their susceptibility to infestation or in their ability to withstand injury. Work was begun along these lines in 1923, but no significant results were secured that year. Consideration will be given, therefore, to the program begun in 1924, continued in 1925, and materially expanded in 1926.

In the absence of any fundamental knowledge regarding the nature of varietal susceptibility to corn borer attack, or of the stage of plant development most likely to be preferred by the borer, the empirical method of attacking the problem seemed most logical at the beginning. The work in 1924 and 1925 was largely confined to the following:

1. A test of distinct varieties of field and sweet corn planted at regular intervals from the first of May to the last of June with the object of determining (a) what commercial varieties of corn could be expected to yield a satisfactory crop when planted on the date giving lowest corn borer infestation, (b) whether varieties differ in percentage of infestation or in the number of borers they can tolerate without serious damage to yield, and (c) the relation between borer population and loss in yield.

2. A test of varieties of field corn with uniform stands of one, two, three, four, five, and six plants per hill with the object of determining (a) the optimum rate of stand at which varieties should be grown for maximum yield of both grain and total nutrients, (b) whether borer population per stalk decreases with an increase in stand of plants per acre and (c) whether the smaller stalks resulting from thick stands are more easily damaged by the borer than the larger stalks of a thin stand.

3. A preliminary comparison of crop rotations permitting the plowing down in June of corn stalks and other debris containing corn borer pupæ, a practice which should be effective in reducing the moth population.

Each of the foregoing studies was made at the Corn Borer Experimental Station at Bono, Lucas County, Ohio. The varietal and date-of-planting studies were also carried on at Sandusky in Erie County and on the Experiment Farm in Paulding County.

In 1926, the work at Sandusky was discontinued, but the varietal and date-of-planting studies were expanded to include plantings at Bono, Wooster, and Columbus, and on the county experiment farms in Paulding and Hamilton Counties, all important corn-growing sections of the state being thus represented in anticipation of the possible future spread of the insect. The rate-of-stand test was continued at Bono and a similar test started on both rich and poor soil at Wooster. The entire agronomic program was considerably expanded in 1926, the more important phases of the work inaugurated being as follows.

1. Tests of different amounts, kinds, and methods of applying fertilizers for corn with the view of hastening the development and maturity of late-planted corn, carried on at Bono and Wooster.

2. A complete life history study of the corn plant, involving both physiological and morphological characters with particular reference to those which may influence the extent of egg deposition or subsequent injury by corn borer larvæ.

3. An extensive program of corn breeding having three principal objectives, namely, (a) a study of a large number of selfed lines and hybrid corns of widely different origin growing under infestation conditions, with the hopeof finding some thatmight possess characters contributing some degree of immunity to infestation or enabling the plant to tolerate infestation. Such plantings were made at Bono, Ohio, and in Essex County, Ontario, the latter being made possible through the excellent cooperation of the Canadian entomologists and agronomists. (b) The development of hybrid corns which can be planted late enough to escape severe infestation and yet mature a good crop of sound corn. (c) The incorporation into these superior strains of those characters which will enable the plant to stand up well under infestation.

4. A study of the fertility value of fresh and leached corn stover, the loss incident to burning, the practicability of using corn stalks in the production of synthetic manure, and the fertility value of such a product.

Dr. Huber[3] has referred briefly to some of the more important findings in the agronomy work. Consideration will be given here in more detail to some phases of this work, with the presentation of certain data and the interpretations that now seem warranted. It should be emphasized that since much of this work is in its preliminary stages few definite conclusions may be drawn.

Table 1 shows the percentage of infestation of 11 varieties of field corn planted at each of six different dates at Bono in 1926. Although the infestation on the whole was four times as high as in 1925 and five times as high as in 1924, the 1926 data are typical of the relative infestations of different varieties and planting dates found in previous years. It will be noted that the list of varieties includes a wide range as regards season required for maturity, ranging from such late maturing varieties as Reid's Yellow Dent and Burr Leaming to such early maturing varieties as Golden Glow and the Ohio-Illinois low ear cross. It is obvious that no consistent relation between the susceptibility to infestation exists between the varieties when different planting dates are compared. It is equally obvious that the severity of infestation decreases markedly as the date of planting is delayed.

In Table 2 are shown similar data for three varieties of sweet corn planted on each of six different dates. The same lack of any consistent difference in infestation between varieties is apparent.

Fig. 1 shows the average percentage of infestation for all planting dates for seven varieties of field corn at Bono for each of three years 1924, 1925, and 1926. The variation in the order of infestation in successive years gives further support to the conclusion that within present commercial varieties there will be found no practical difference in susceptibility to infestation.

Fig. 2 shows by graphs the average percentage infestation for all field corn varieties for each planting date at Bono for each of the three years. Fig. 3 shows the relative infestation for each date where the infestation of the earliest planted corn is taken as 100. It is apparent that the infestation of the June 7 and June 11 plantings was relatively higher in 1926 than the nearest corresponding dates in the previous years. This fact is explainable, at least in part, by the lateness of the season in 1926, which resulted in the moths emerging nearly a week later than in the previous year.

The yields of dry shelled corn for the normal planting dates secured in the first two years at Bono and Sandusky and the first year at Paulding are given in Table 3. While there are some exceptions, the general conclusion may be drawn that when planted at the normal

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[3] See preceding paper.

TABLE 1.—*Infestation of field corn planted at different dates at Bono in 1926.*

Variety	May 10	May 20	May 29	June 7[a]	June 11[a]	June 22[a]	Average
	%	%	%	%	%	%	%
Van Wye's	72.6	68.2	60.5	50.6	25.7	1.2	46.5
Golden Glow	69.7	64.1	58.4	47.6	25.4	3.4	44.7
Ohio-Illinois low ear cross	60.9	58.4	48.7	45.8	15.3	8.1	39.5
Medina Pride	70.3	67.3	52.7	38.7	26.9	1.8	42.9
Ohio selection low % grain	65.3	60.3	52.8	35.0	34.2	1.3	41.5
Clarage	71.8	69.9	64.4	39.8	31.9	1.2	45.8
Ohio selection high % grain	69.3	57.8	61.5	48.4	29.0	2.5	44.7
Leaming	68.9	56.3	50.2	44.6	27.8	5.4	42.2
Burr Leaming	65.5	52.3	48.8	28.8	23.9	7.8	37.8
Reid's Yellow Dent	57.3	59.2	46.8	29.4	17.2	7.8	36.3
Champion White Pearl	54.7	53.0	52.9	25.2	27.7	10.2	37.3
Average	66.0	60.6	53.9	39.4	26.1	4.6	

[a]Preliminary data are from single plats; data for earlier dates are averages of triplicate plats.

TABLE 2.—*Infestation of sweet corn planted at different dates at Bono in 1926.*

Variety	May 10	May 20	May 29	June 9	June 19	June 29	Average
	%	%	%	%	%	%	%
Golden Bantam	21.1	10.4	25.1	10.4	1.8	1.6	11.7
Red Evergreen	23.0	16.5	18.3	8.9	0.5	4.0	11.7
Stowells Evergreen	22.3	15.8	15.8	5.8	1.8		11.7
Average	22.1	14.2	19.7	8.4	1.4		

TABLE 3.—*Yield in bushels of shelled corn[a] for normal planting date.[b]*

Variety	Location and year				
	Bono		Sandusky		Paulding
	1924	1925	1924	1925	1925
Reid's Yellow Dent	51.6	—	52.0	—	—
Burr Leaming	62.4	116.5	51.7	50.4	79.5
Leaming	—	96.6	47.1	43.8	73.6
Clarage	48.7	94.1	40.7	43.0	73.4
Ohio selection low % grain	41.1	90.3	41.6	—	—
Van Wye	43.8	83.3	—	35.1	—
Ohio selection low ear	—	—	—	29.6	49.6
Golden Glow	—	77.5	—	34.6	73.6
Silver King	46.7	—	41.0	—	62.2
N. W. Dent	40.9	49.7	16.1	—	—
Stone's Calico	—	—	46.0	—	—
White Cap	—	—	—	—	70.3

[a]Air-dry in 1924; reduced to 15½% moisture in 1925.

[b]Average of first two planting dates May 8, 9, or 10, and May 19 or 20.

date of May 10 to 20 the later maturing varieties can be expected to produce the highest yields of dry corn. Moreover, the superiority of Burr Leaming, a double cross developed by Jones in Connecticut, is apparent in each of the tests.

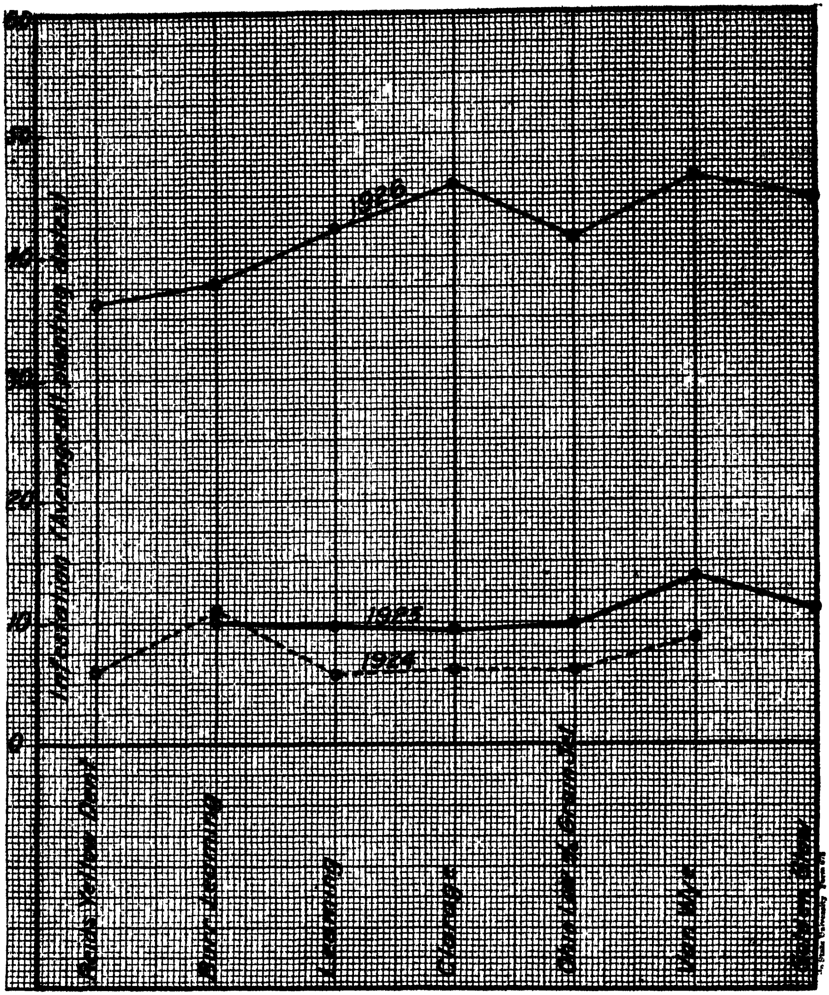

FIG. 1.—Infestation of corn varieties in 1924, 1925, and 1926.

Table 4 shows similar yield data for the last planting made in each of these tests. While the yields for the late maturing varieties have on the whole been reduced most by late planting, the conclusion can scarcely be drawn that for late planting the earlier maturing varieties offer any advantage so far as actual yield of dry corn is concerned. Burr Leaming has shown up especially well, even when planted at this very late date. Of course, the moisture carried at husking time by the later varieties is too high (Table 5) to permit their being classed as sound corn. This raises the question whether more effort

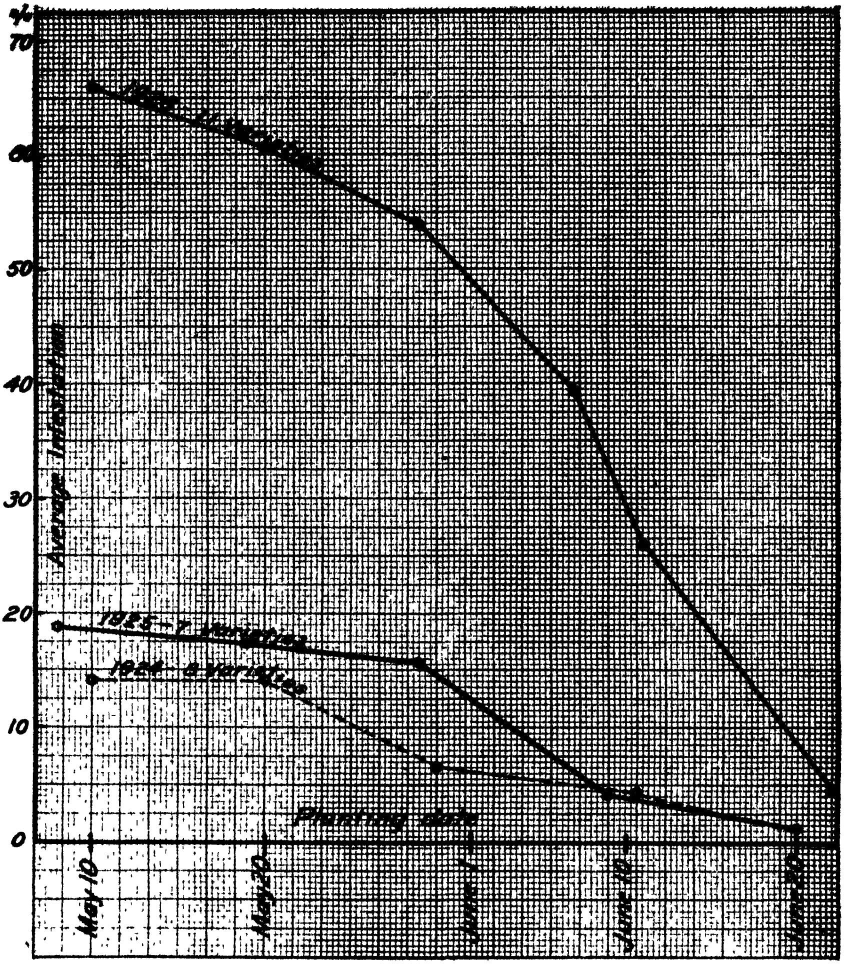

FIG. 2.– Average infestation of corn for different planting dates in 1924, 1925, and 1926.

might not well be directed toward the development of better methods for handling immature corn. Recent experiments at the South Dakota Station indicate that soft corn may be fully equal to mature corn for feeding purposes.

In the rate-of-planting studies the Burr Leaming and Clarage varieties have been grown for two years with uniform stands of from one to six stalks per hill. The results secured for 1925 and 1926 have been conflicting. The first year's data indicated that with thick planting there was a reduction of the percentage of infestation and of the borer population per stalk. In 1926, there was no significant

TABLE 4.—*Yield in bushels of shelled corn*[a] *for last planting date.*[b]

Variety	Location and year				
	Bono		Sandusky		Paulding
	1924	1925	1924	1925	1925
Reid's Yellow Dent	30.7	—	29.9	—	—
Burr Leaming	47.5	74.6	34.9	37.2	56.4
Leaming	36.7	70.1	38.0	33.5	62.7
Clarage	32.0	67.6	34.2	33.2	63.4
Ohio selection low % grain	34.6	57.3	33.9	—	—
Van Wye	26.7	68.0	—	34.0	—
Ohio selection low ear	—	—	—	31.9	48.0
Golden Glow	—	74.9	—	33.2	65.5
Silver King	28.2	—	38.5	—	56.3
N. W. Dent	24.0	48.9	13.3	—	—
Stone's Calico	—	—	39.5	—	—
White Cap	—	—	—	—	56.2

[a] Air-dry in 1924; reduced to 15½% moisture in 1925.

[b] June 19 or 20 at Bono and Sandusky; June 10 at Paulding.

TABLE 5.—*Maturity of late planted corn*[a] *as indicated by percentage of shrinkage or moisture.*[b]

Variety	Location and year				
	Bono		Sandusky		Paulding
	1924	1925	1924	1925	1925
	%	%	%	%	%
Reid's Yellow Dent	44.5	—	57.0	—	—
Burr Leaming	41.0	39.7	53.0	54.6	43.7
Leaming	39.5	39.3	49.0	55.0	37.6
Clarage	32.0	35.3	45.5	49.8	31.1
Ohio selection low % grain	33.5	33.6	45.5	—	—
Van Wye	27.5	28.0	—	41.2	—
Ohio selection low ear	—	—	—	40.4	25.1
Golden Glow	—	34.2	—	39.4	35.8
Silver King	30.5	—	40.5	—	31.3
N. W. Dent	23.0	29.4	36.0	—	—
Stone's Calico	—	—	32.5	—	—
White Cap	—	—	—	—	33.3

[a] Planted June 19 or 20 at Bono and Sandusky and June 10 at Paulding.

[b] 1924 data represent shrinkage under dry storage from husking time until spring. 1925 data represent moisture content at husking time.

TABLE 6.—*Relative weights of ears from infested and from non-infested stalks at Bono in 1926.*

Planting date	Relative ear weights	
	Non-infested	Infested
May 10 (33 plats)	100	90.86
May 20 (33 plats)	100	92.57
May 29 (33 plats)	100	94.81
June 7 (33 plats)	100	94.47
June 11 (33 plats)	100	93.74

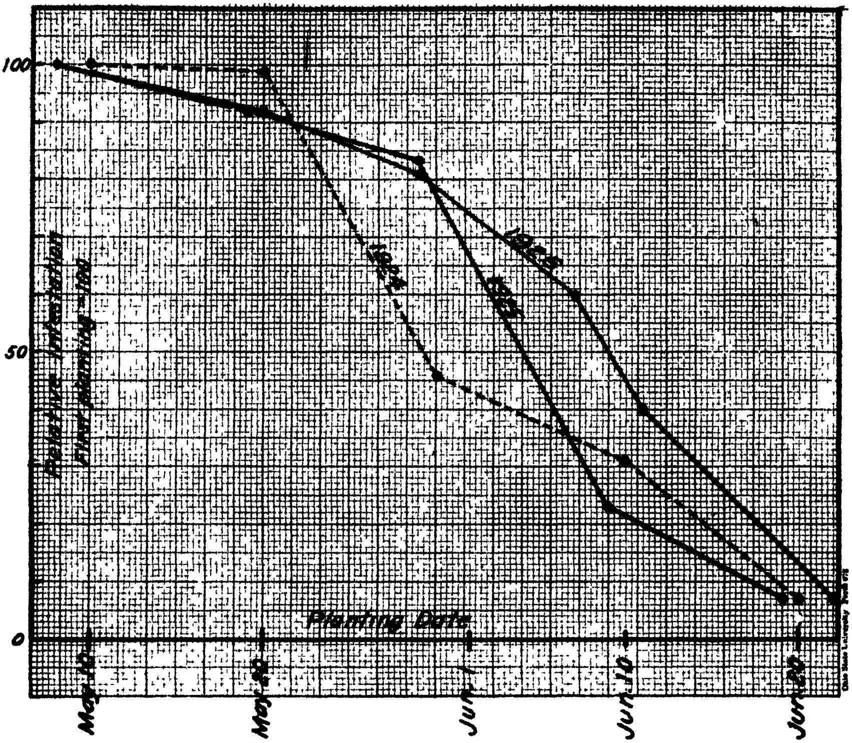

FIG. 3.—Relative infestation of corn for different planting dates in 1924, 1925, and 1926.

difference between the infestation of either variety planted at the different rates. Further work will be necessary to determine which result is reliable.

One question of considerable importance upon which little information is yet available is the relation existing between percentage of infestation, borer population, and reduction in yield. Table 6 gives some data bearing on this point. It shows the relative weights of ears from infested and from non-infested stalks from a part of the 1926 "varietal and date-of-planting" plats at Bono. It will be noted that the ears from infested stalks range from 5.19 to 9.14% lighter in weight than those from non-infested stalks. At the time the table was prepared the data on borer population of the infested stalks were not available. The actual number of borers present per stalk in the different plantings as later reported were as follows: May 10, 1.65; May 20, 1.60; May 29, 1.45; June 7, 1.02; and June 11, 1.14. It is to be expected that as the borer population per stalk increases, the reduction in yield will increase, possibly at a relatively higher rate.

Table 7 shows the relation of infestations, borer populations, and percentages of broken stalks for the varietal and date-of-planting study made in Essex County, Ontario. The data indicate a direct relation between the percentage of broken stalks and the average borer population per stalk That some varieties or strains of corn may be able to tolerate a given number of borers with less breakage of stalks and probably less reduction in yield than others is indicated by the data shown in Table 8. The rugged character of the Burr Leaming stalks as compared to the more slender stalks of the smaller growing varieties probably accounts for the difference in breakage. Ruggedness of stalk is a character that is being given considerable emphasis in the corn breeding program which will be discussed later.

TABLE 7.—*Relation of infestation, borer population, and broken stalks for different planting dates in Essex County, Ontario, 1926.*

Average of eight varieties.

	Date of planting	Percentage infested	Borer population per stalk	Percentage of stalks broken
May . .	26	92.8	5.85	19.8
June	7	95.2	6.42	27.0
June	17	65.6	1.90	7.1

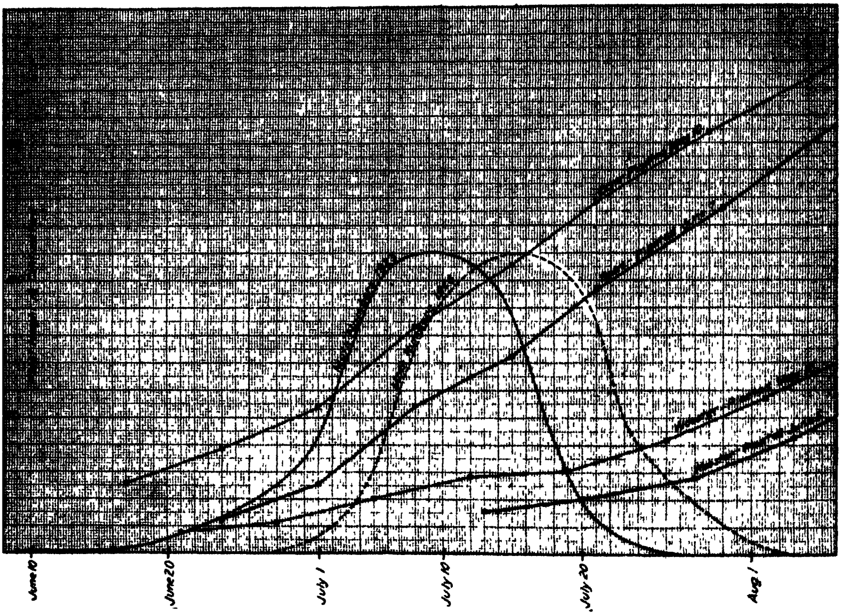

FIG. 4.—Rate of increase in height of Burr Leaming corn for each of two planting dates at Wooster and at Bono in relation to relative number of moths flying.

Attention has been called to the relatively high infestation of the June 7 and June 11 plantings at Bono in 1926 as compared to previous years and an explanation offered in the lateness of emergence of the moths. Fig. 4 shows the approximate relative numbers of moths in flight during the 1925 and 1926 seasons, the curves being based upon emergence data supplied by the entomologists and upon the assumption that a single moth remains in flight for a period of two weeks. The figure also shows the rate of growth of Burr Leaming corn as indicated by height of plant for both an early and a late date of planting at Bono and at Wooster. It will be noted that the rate of growth of the plants at Bono was much more rapid than at Wooster and that during the period representing the peak of the moth flight the corn planted June 7 at Bono was actually larger than that planted 23 days earlier at Wooster. Since the mean monthly temperature at the two locations varied less than 1.5 degrees for May, June, and July, and since the monthly rainfall was considerably less for each month at Bono than at Wooster (being below normal at both places), it would appear that this difference in rate of growth was due to soil rather than to climatic differences. The soil at Bono is a heavy, very fertile, Toledo silty clay, that at Wooster, a medium textured Canfield silt loam of only moderate fertility. Soil differences may prove to be an important factor in determining the severity of corn borer infestation. It is possible that the correlation brought out in the ecological studies between the severity of corn borer infestation and forest types may be due as much to edaphic factors affecting the rate of growth of the corn plant as to the influence of climate upon the insect. This view is not encouraging to the central corn belt states with their large areas of highly fertile soils.

TABLE 8.—*Borer population and broken stalks for different varieties in Essex County, Ontario, 1926.*

Average of three planting dates.[a]

Variety	Borer population per stalk	Percentage of stalks broken
Minnesota 16	6.0	23.3
Minnesota 24	4.6	21.5
Clarage	4.2	19.8
Minnesota 22	3.8	18.8
Bailey...	5.7	16.5
White Cap. ...	4.7	16.5
Golden Glow	4.3	15.8
Burr Leaming	4.3	11.6

[a] Each variety represented by triplicate plats on each of three planting dates.

Previous work having indicated the efficacy of late planting in reducing infestation, experiments were started at Bono and Wooster in 1926 to determine the extent to which the maturity of late planted corn might be hastened by the proper choice and placing of fertilizers. These experiments involved a comparison of varying amounts of acid phosphate and 0–12–4 and 3–12–4 mixed fertilizers. Broadcast applications were compared with hill applications and with split applications, where a part was broadcasted and the remainder placed in the hill. The hill applications were made through the fertilizer attachment of a Janesville corn planter at Wooster and by hand at Bono. In both cases the fertilizer was spread in a band approximately ¾ inch above the seed, the location suggested by Truog as being least inimical to germination. Three varieties of corn, Burr Leaming, Clarage, and Golden Glow, all planted June 5, were included in the test at Bono. In the Wooster experiment only one variety, Burr Leaming, was used, but two plantings were made, one on May 15 and one on June 5. Throughout the season at Bono there

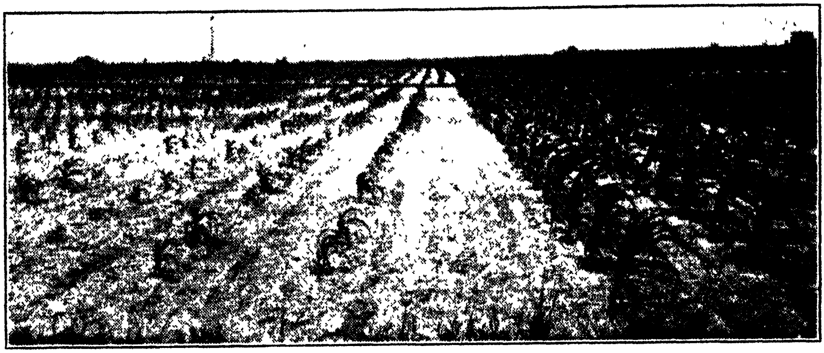

FIG. 5.—Photograph taken July 9 of May 15 planting. The plat at the left received 225 pounds per acre of 0–16–0 broadcast; the plat at the right, 400 pounds per acre of 3–12–4 in the hill.

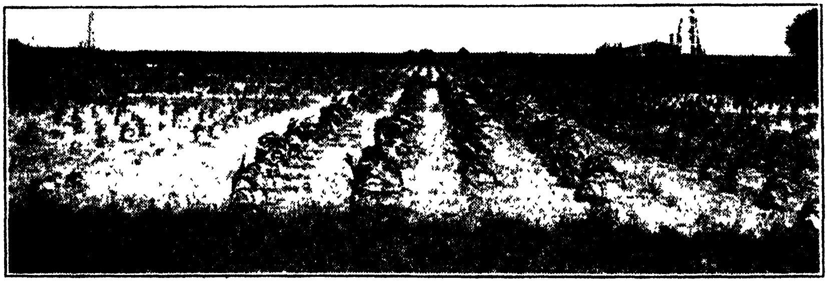

FIG. 6.—Photograph taken July 9 of May 15 planting. The plat at the left received 225 pounds per acre of 0–16–0 broadcast; the plat at the right, 225 pounds per acre of 0–16–0 broadcast and 8 tons per acre of shed manure; the center plat, the same treatment as that on the right plus 100 pounds per acre of 3–12–4 in the hill.

was no visible evidence that any of the fertilizer treatments were affecting the development of the crop. Yield and moisture data now being secured may show differences which could not be detected in the appearance of the crop. The results at Wooster were quite different.

TABLE 9.—*Development of Burr Leaming corn as affected by fertilizer treatment at Wooster, 1926.*

Planting	Treatment,			Date			
date	Formula	pounds	Application	Tasseled	Silked	Milk	Dent
May 15	0–12–0	300	Broadcast	Aug. 13	Aug. 20	Sept. 7	Sept. 28
May 15	3–12–4	200	Hill	Aug. 3	Aug. 10	Aug. 31	Sept. 21
June 5	0–12–0	300	Broadcast	Aug. 24	Aug. 30	Sept. 23	Oct. 1 (Frost)
June 5	3–12–4	200	Hill	Aug. 12	Aug 19	Sept. 2	Sept. 23

Fig. 5 is a field photograph taken July 9 of the May 15 planting and shows on the left a plat receiving a broadcast application of 225 pounds of 16% acid phosphate and on the right 400 pounds of 3–12–4 in the hill. Fig. 6 shows on the left a plat receiving 225 pounds of acid phosphate broadcast, on the right a plat receiving the same phosphate treatment together with 8 tons of shed manure, and in the center a plat receiving in addition to similar manure and phosphate treatments 100 pounds of 3-12-4 in the hill. Table 9 shows a comparison of the time required to reach various stages of development for plats receiving 300 pounds of 0-12–0 (225 pounds of 0–16–0) broadcast and 200 pounds of 3-12–4 in the hill for both planting dates. Attention is called to the fact that with corn planted June 5 and fertilized with 200 pounds of 3-12-4 in the hill the ears were dented five days earlier on the average than corn planted May 15 and given a broadcast application of acid phosphate. In this work, increasing the broadcast application of acid phosphate up to 900 pounds per acre failed to hasten development or maturity appreciably. Broadcast applications of 0-12–4 and 3-12-4 were similarly without effect. Hill applications hastened development in all cases, the effectiveness of the 0–12-0, the 0 12-4, and the 3–12–4 increasing in the order named. Apparently there are some soil and seasonal conditions when the proper choice and placing of the fertilizer may aid greatly in hastening the maturity of late planted corn. Unfortunately, it is also possible that, by hastening early development, fertilizer treatment may increase the severity of infestation. In the foregoing work provision was made for sampling all plats at regular weekly intervals for the purpose of making determinations of height, leaf area, weight, and chemical composition.

Fig. 7 shows the leaf area curve for differently fertilized plats of

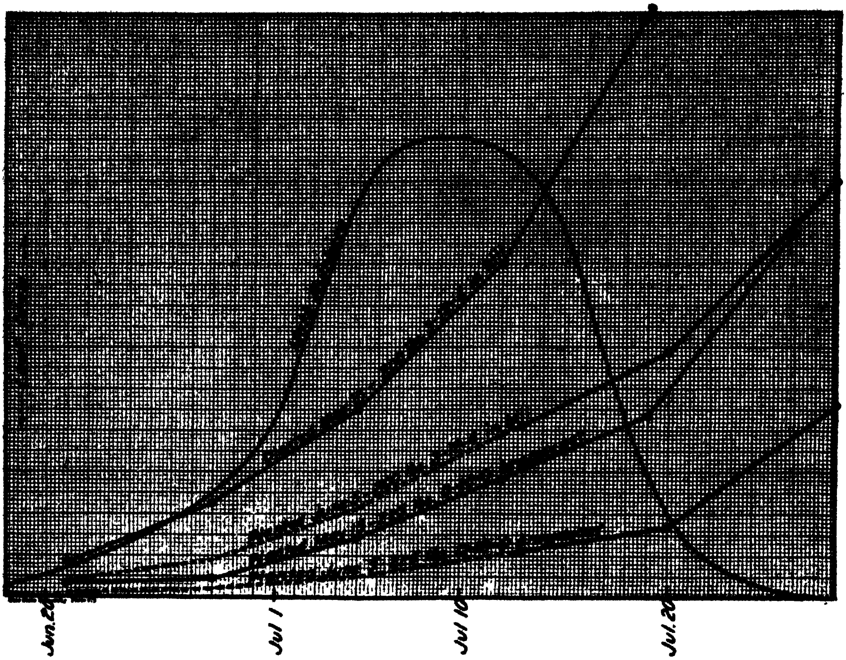

FIG. 7.—Effect of fertilizer on leaf area of Burr Leaming corn at Wooster.

both plantings. The curve showing the number of moths in flight at Bono in 1925 is superimposed for comparison. If size of plant is the predominant factor in determining the preference of the moths for early planted corn, then it is obvious that the corn planted June 5 and fertilized with 200 pounds of 3–12–4 in the hill should attract more moths than the corn planted May 15 and receiving the broadcast treatment with acid phosphate. The work in 1927 will be expanded to determine whether a delayed side dressing with the proper fertilizers may not hasten development after the peak of the moth flight has passed and also whether the date of planting can be delayed beyond June 5 and still mature the crop with less opportunity for infestation.

Corn breeding work in relation to the corn borer problem was begun in 1926 and was in charge of M. T. Meyers, working in cooperation with the Farm Crops Department of Ohio State University and with the United States Department of Agriculture. The splendid cooperation of the corn breeders of 12 states in supplying many in-bred lines and crosses for use in this work has made possible the development of an extensive program. The source and amount of breeding material thus made available, together with that originating

TABLE 10.—*Source and amount of breeding material in 1926.*

State	Persons	Field corn		Sweet corn	
		In-bred lines	Crosses	In-bred lines	Crosses
Indiana	G. N. Hoffer	55	20	16	
Illinois	C. N. Woodworth	11			
Iowa	M. F. Jenkins	7			
	H. A. Wallace		3		
Nebraska	T. A. Kiesselbach	8			
Kansas	A. M. Brunson	55	11		
Minnesota	H. K. Hayes	10	17		
Wisconsin	C. R. Burnham	7		13	
New York	R. G. Wiggans	38	13		
Connecticut	D. F. Jones	7	2	2	2
U. S. D. A.	F. D. Richey	62		110	
Ohio		919	150	526	75
Total		1,179	216	667	77

in Ohio, is shown in Table 10. With such an abundance of material it was essential that a careful study be made of the performance of the various pure lines and crosses with the object of eliminating those offering least promise. Plantings were made at Columbus, Bono, and at Tilbury, Ontario, in the heart of the area of heavy corn borer infestation. These included a total of 2,715 plats of pure lines and 1,284 plats of hybrids. Complete notes were kept of all characters which were thought to be of importance in breeding corn for corn borer conditions as well as those of general agronomic interest. The information secured will permit the elimination of a large number of undesirable lines and next year's program will go forward with less wasted effort. The 1926 program included the making of 10,000 selfs, 2,000 single crosses, and 600 double crosses.

This year's observation of lines and crosses grown in corn borer territory in Ohio and Canada shows that the possession of a slender, weak stalk is accompanied by severe damage. Only those plants showing sturdy, thick-set stalks and which remained vegetative after the ear had dented were at all able to withstand damage. Even these succumbed when borer population reached a high figure. Sufficient evidence has been secured, however, to warrant the belief that crosses can be made between pure lines which will be able to withstand a moderate amount of infestation.

No variety or strain has as yet exhibited immunity to attack. The possibility of securing such a true resisting sort, however, has not been exhausted. Some evidence was secured at the Bono laboratory this year that the corn plant at a certain stage of development gives off an odor attractive to the moths while at other stages such attraction is reduced or lacking. Anyone familiar with the enormous range of variable characters of the corn plant may be hopeful that a line may be discovered in which this attractive substance is either absent or of lower potency. It is also possible that life history studies of pure lines will reveal some lines which may be less subject to infestation because of relatively slow development up to the time that most of the moths have deposited their eggs. In general, however, the breeder will undoubtedly devote most of his energy to the finding of that fortunate combination or combinations giving a strain or strains which can be planted late enough to escape corn borer infestation, and still have sufficient vigor and sturdiness of stalk to tolerate some infestation and mature a good yield. The past year's work has given considerable promise that this objective may be realized.

TABLE 11.—*Pounds of fertility constituents lost in synthetic manure process and in burning.*

	Total	Nitrogen	Phosphorus	Potassium
Fresh stover	2,000	18.0	2.55	16.2
Adco	150	13.7	5.10	0.9
Total		31.7	7.65	17.1
Synthetic manure	4,200	17.8	7.90	6.9
Loss		13.9	—.25	10.2
Fresh stover	2,000	18.0	2.55	16.2
Sulfate of ammonia	65	13.2	—	—
Total		31.2	2.55	16.2
Synthetic manure	4,070	13.8	2.87	6.5
Loss		17.4	—.32	9.7
Fresh stover	2,000	18.0	2.55	16.2
Ashes	242	.4	2.49	13.5
Loss		17.6	.06	2.7

In most of the corn borer infested territory clean-up regulations have been adopted calling for the complete disposal of all corn stalks and refuse by either shredding, ensiling, working into manure, burning or plowing under completely. Farmers have repeatedly raised the question, in regard to burning stalks, as to the loss in fertility value. There has also been much recent discussion of what constitutes the proper utilization of not only corn stover but also straw and other highly carbonaceous residues where these are returned to the land in order that their maximum fertility value may be realized without the accompanying harmful effects due to a reduction of soil nitrates. With these questions in mind a field experiment was begun this year at Wooster in which the fertility value of fresh and leached stover is being compared with corn stover ashes and with synthetic manure made by composting corn stover with "Adco" according to the English method or with limestone and sulfate of ammonia carrying an equal amount of soluble nitrogen. About all that can be said about this work is that the results secured in the foregoing methods of making synthetic manure appear about equal.

Table 11 shows the chemical composition of the fresh corn stover, of the synthetic manure produced by the two methods, and of the ashes produced by burning the stover. The method of composting employed, using only 1 ton of stover in a pile with an abundance of water and no provision to prevent leaching, was probably responsible for the losses in nitrogen and potash which were so heavy as to render either method of producing the synthetic manure of doubtful economy. There is little possibility of any wide adoption of the synthetic manure process on the general farm unless the amount of water required may be materially reduced below what has been commonly recommended. An experiment is now under way at Wooster aiming to determine the least amount of water that can be used for the successful completion of the process.

The principal phases of the agronomic corn borer research program have now been considered. The writer wishes to call attention again to the preliminary character of much of the work that has been done so far. Immediate accomplishments are not to be anticipated. The suggestion is offered to workers in those states not yet infested but anticipating infestation, that there are certain phases of agronomic corn borer research which can be successfully carried on in uninfested territory. It is to be hoped that a definite effort will be made by workers embarking upon the corn borer problem to correlate the work of the different institutions, thereby eliminating unnecessary duplication of effort and building the future program upon what has already been accomplished.

ECONOMICS OF PERMANENT PASTURE IMPROVEMENT[1]

J. W. White[2]

Lack of knowledge concerning the economic value of highly developed pastures has been responsible for the general belief that the more fertile type of farm land can be utilized to better advantage in a rotation system. Field plat experiments conducted by the Pennsylvania Agricultural Experiment Station dealing with the development and maintenance of Kentucky bluegrass pastures on three distinctly different soil types have thrown a new light on this important subject and have led to the conclusion that highly developed Kentucky bluegrass pastures are worthy of a more prominent place in the economic scheme of farm management.

The purpose of this paper, therefore, is to present in a brief manner the data furnished by these experiments in support of the creation and maintenance of such pastures on land similar to that now occupied by cultivated crops. Details of these three experiments have previously been published in Bulletin 195 of the Pennsylvania Station. This paper, therefore, will deal with such data as seem to bear directly on the economic phases of the subject.

Previous pasture studies as conducted by the agricultural experiment stations northeast of the prairie country have dealt largely with the rejuvenation of old pastures of extensive acreage in an attempt to stimulate the growth of existing grasses which vary in species and nutritive value in accordance with the particular soil conditions. In many such experiments, often called pasture demonstrations, the grasses have not responded to soil amendments, due largely to the poor physical condition of the soil. Such pasture studies are largely responsible for the general belief that liberal application of lime and mineral fertilizers is not an economic practice, especially in regard to the use of mineral nitrogen.

NUTRITIVE VALUE OF KENTUCKY BLUEGRASS

The wide range in nutritive value of green immature pasture grasses has not been fully realized by producers of livestock. As a result, their attention has been directed to the development of existing grasses rather than to an attempt to introduce into their pastures more desirable species. A comparison of the nutritive value of immature Kentucky bluegrass with other pasture grasses (Table 1) shows that it excels in nutritive value all other eastern pasture grasses. In fact, it contains a higher percentage of digestible protein than either red clover or alfalfa. Data presented in Table 6 show that a well fertilized blue grass pasture is capable of furnishing three times the digestible crude protein supplied by a four-year rotation of corn, oats, wheat, and grass. It will also be seen that an equal area of blue-grass pasture is capable of producing more total digestible nutrients than is produced by a grain rotation on the same soil. The known labor cost of producing a grain rotation as compared to pasture maintenance should leave no doubt in the mind of the reader concerning the economy of pasture feeding.

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[1] Paper read at the meeting of the Society held in Washington, D. C., November 18, 1926. Contribution from the Department of Agronomy, Pennsylvania State College, State College, Pa.

[2] Professor of Soil Technology.

TABLE 1.—*Nutritive value of Kentucky bluegrass compared with other pasture grasses and legumes.*[a]

Computed on the basis of green roughage as pounds of digestible nutrients in 100 pounds of dry matter.

Grass or legume	Crude protein	Carbohydrates	Fat	Total nutrient
Kentucky bluegrass (before heading)	15.5	43.6	3.4	66.9
Kentucky bluegrass (headed out)	8.3	45.8	1.9	57.9
Kentucky bluegrass (after bloom)	4.3	50.2	1.6	58.2
Canada bluegrass	3.9	51.8	1.2	58.4
Red top	4.8	50.8	1.5	59.0
Orchard grass	5.8	45.5	2.0	55.1
White clover	14.2	44.0	2.2	63.3
Red clover (in bloom)	9.0	50.1	2.5	65.8
Alfalfa (in bloom)	12.7	41.7	1.1	57.1
Average of 44 grasses	5.6	48.2	1.6	57.4
Average of 25 legumes	13.6	42.7	1.7	63.1

[a] Computed from Henry's Feeds and Feeding, Table III, p. 738.

ADAPTABILITY OF KENTUCKY BLUEGRASS TO EASTERN SOILS AND CLIMATIC CONDITIONS

The remarkable natural development of Kentucky bluegrass in the vicinity of Lexington, Kentucky, is due to soil conditions rather than to more favorable climate. This particular soil, formed from the weathering of phosphatic limestone, contains in the plowed surface 15,000 pounds per acre of phosphorus compared to 1,400 pounds per acre found on an average in four of the most important Pennsylvania soils. The Kentucky soil contains 5,000 pounds of easily soluble phosphorus (soluble in N/5 HNO_3) as compared to 18 pounds per acre 7 inches in Pennsylvania soils.

The climate of the northeastern section of the country with its cooler summer months is more favorable to the best development of bluegrass than is that of Kentucky. Throughout the northern states Kentucky bluegrass may be found well established in limited areas, along roadsides, in well kept lawns, and in the vicinity of barnyards. At the Pennsylvania Experiment Station the division strips between the old fertilizer plats have maintained a heavy growth of Kentucky bluegrass for over half a century. There is, however, no extensive pasture land in the state which supports a bluegrass turf comparable with that found in the bluegrass regions of Kentucky. These observations, together with the data secured as the result of the pasture studies reported in the succeeding pages, indicate that the best development of Kentucky bluegrass is dependent upon a soil equal in fertility to that required for cultivated crops.

PENNSYLVANIA PERMANENT PASTURE EXPERIMENTS

The pasture experiments are located on Dekalb, Volusia, and Westmoreland soils which are representative of 71% of the Pennsylvania soil area. The plat studies were begun on Dekalb soil at Snow Shoe, Centre County, in 1916; and on Volusia soil at Springfield, Bradford County, and on Westmoreland soil at Arden, Washington County, in 1918. The plats, of one-tenth acre each, were treated with various combinations of mineral fertilizers, lime, and manure. The soil was seeded to Kentucky bluegrass, sweet clover, and white clover.

NATURE OF SOILS AND CONDITION OF LAND AT BEGINNING OF EXPERIMENTS

The three experiments were established on abandoned farm land which was in a state of depletion. There are thousands of such acres throughout the state. The Snow Shoe experiment on Dekalb soil was located on an old field abandoned for 40 years, the soil having become incapable of supporting even a growth of native weeds. The Bradford County experiment, located at Springfield, was on the Volusia group of soils, recently divided into Volusia, Wooster, and Canfield. The field had been abandoned for many years, the plant growth being largely checked by excessive soil acidity. The Washington County experiment at Arden, on Westmoreland soil, was located on an old abandoned timothy field.

FERTILIZING MATERIALS USED AND MANNER OF APPLICATION

Limestone was applied to each field in sufficient amount to supply the 60-mesh material necessary to meet the Veitch lime requirement equivalent to 3 tons of limestone on Dekalb soil, 6 tons on Volusia, and 3.2 tons on Westmoreland soil.

The nature and rate in pounds per acre of fertilizing materials used were as follows: 48 pounds nitrogen as nitrate of soda, 65 pounds phosphoric acid as acid phosphate, and 50 pounds potash as muriate of potash. Farm manure was applied at the rate of 6 tons per acre, except on Dekalb soil where 4 tons were used. Manure was reinforced with 30 pounds of 16% acid phosphate per ton of manure on Volusia and Westmoreland soil and 70 pounds per ton of manure on Dekalb soil. The fertilizers and manure were applied biennially. The fertilizers were top-dressed by hand and the manure applied with manure spreader except the 4-ton applications which were applied with manure forks.

For the sake of brevity, the following symbols are used in the succeeding tables: N = nitrate of soda, P = acid phosphate, M = manure, K = muriate of potash, and Ca = limestone.

METHODS OF SECURING YIELDS

The pastures were mowed in the early summer when the bluegrass was in bloom. The field-cured hay was then raked and weighed. The second growth of bluegrass was not harvested each year. It was difficult to secure accurate yields of the subsequent growth, due to the difficulty of cutting and raking the relatively short grass. However, during the progress of the studies, the later growth was harvested several times by use of the mowing machine, also by clipping representative areas with lawn shears. The data thus secured showed that the second growth was 54% of that secured in the first cutting. Data secured from somewhat similar studies at the Cornell Experiment Station (Bulletin 424) showed that the growth of Kentucky bluegrass during the second half of the season was 44% of that produced during the spring and early summer. The yields given in Table 2 include the first cutting plus 40% added for the estimated second growth. The Cornell studies also show that bluegrass under pasture conditions, that is cut at five periods, gave 13% greater yields than when cut as meadow hay.

TABLE 2.—*Average annual yields per acre of Kentucky bluegrass on three types of soil and with various fertilizer treatments.*

Plat treatment	Dekalb soil		Volusia soil		Westmoreland soil	
	Air-dry weight	Equivalent green weight	Air-dry weight	Equivalent green weight	Air-dry weight	Equivalent green weight
Untreated[a].	——	——	88	295	871	2,929
Ca........	96	323	1,402	4,712	1,951	6,558
CaP......	2,071	6,961	1,831	6,113	2,868	9,640
CaPK.....	2,521	8,474	2,672	9,107	3,095	10,403
CaPKN...	3,530	11,865	4,120	13,428	4,326	14,541
CaMP	2,488	8,363	3,609	12,131	3,492	11,822

[a] Average of three plats.

DISCUSSION OF RESULTS

On the untreated plats, the soils, on an average, have not produced a growth of grass of sufficient economic importance to justify the use of the land for pasture without manurial treatment. However, on the limed soils without further treatment there is a significant growth of pasture grasses which varies in accordance with the residual fertility of the three soils. The failure of limestone to produce grass on Dekalb soil is due to the depleted condition of the soil with respect to phosphorus and in no sense to the inactivity of the lime applied. When acid phosphate is applied to the limed soils there is a marked increase in the yields of grass on Dekalb soil. The average annual increased yields of bluegrass in excess of lime used alone are as follows: Dekalb soil, 1,975; Volusia soil, 429; and Westmoreland soil, 917 pounds per acre. In any phase of eastern farming lime and acid phosphate may be considered the foundation upon which to build a system of permanent agriculture.

The question of economic importance involves the additional use of potash and nitrogen, whatever system of farming may be under consideration. The nature of the cropping system, together with the particular soils under consideration, determine the economic use of these materials and more especially the use of soluble nitrogen. The three soils show a distinct difference in the response to applications of potash as measured by the average annual increased yields of bluegrass where potash is supplied in addition to lime and acid phosphate. Increased yields from CaPK over CaP are as follows: On Dekalb soil, 450 pounds or 21%; on Volusia soil, 841 pounds or 46%; and on Westmoreland soil, 227 pounds or 8%. In like manner the response to applications of mineral nitrogen is as follows: CaNPK over CaPK on Dekalb soil, 1,009 pounds or 40%; on Volusia soil, 1,448 pounds or 54%; and on Westmoreland soil, 1,231 pounds or 39%. The value of potash on Dekalb and Volusia soils and nitrogen on each soil is shown by the above figures.

CARRYING CAPACITY AND COMPUTED VALUE OF KENTUCKY BLUEGRASS

The value of several differently treated pasture areas may be estimated in two ways: First, by feeding an equal number of grazing animals and determining the value of the products produced for a definite period; and, second, by determining the total weight of grasses produced on each area and computing the known feeding value in terms of digestible nutrients required for maintenance and production of animal products, such as milk, beef, pork or mutton, and wool. The first method is open to objection because of the variability of animals even of the same breed where a comparatively large number have to be included in each feeding lot. The increased number of animals also requires larger feeding areas which introduce a serious error of soil variability.

The second method has the advantage because smaller areas may be used, such as long narrow plats which are known to reduce the error of soil variation. The second method is used here, although it involves more or less theoretical consideration. The yields of bluegrass as determined are computed in terms of fresh green Kentucky bluegrass available for grazing animals for a period of five months. The yield of grass for the second cutting is taken at 40% of that produced at the first harvest, instead of 54% as actually found, to allow for the grass destroyed under grazing conditions. The Cornell studies, cited earlier, show that when Kentucky bluegrass is frequently cut it yields 13% more than when cut less frequently, as in the case of a meadow It may be assumed, therefore, that the yields of grass shown in Table 2 would be available for grazing animals.

METHOD OF COMPUTATION

The feeding value and carrying capacity are estimated in terms of dairy cattle producing different quantities of milk. Eighty pounds of green grass per head each day are used as the basis of computation. This figure represents the maximum amount of grass that would likely be consumed per day, and this quantity contains sufficient digestible crude protein (2 96 pounds) to meet the demands for maintenance and milk production of an average 1,200-pound dairy cow producing from 35 to 40 pounds of 3 5% milk per day. Three types of 1,200-pound cows are used in the computations, those producing 20, 35, and 50 pounds of milk per day. In making these computations, it is recognized that a cow producing more than 25 pounds of milk per day should be provided with sufficient concentrates other than the feed secured in the pasture to furnish the necessary total digestible nutrients for maintenance and production.

Feeding concentrates to grazing dairy cattle has been shown to be an economical practice. The animal is kept in better physical condition throughout the summer and goes into the winter feeding period more capable of a uniformly high milk production. A 1,200-pound cow, yielding daily 30 pounds of 3.5% milk, will require for maintenance and production an average of 2.49 pounds digestible crude protein and 18.51 pounds total digestible nutrients. Eighty pounds of green Kentucky bluegrass will furnish 2.96 pounds digestible crude protein and only 12 72 pounds total digestible nutrients (Henry's Feeds and Feeding, pp. 747 and 739).[3] The difference of

5.79 pounds of total digestible nutrients should be supplied by supplementary feed.

Green pasture grass, especially Kentucky bluegrass, is a high protein feed with a nutritive ratio of 1:3.3 which should be modified with supplementary feed to a ratio of at least 1:6.6. Table 3 shows the computed value of pasture on the basis of five months of continuous grazing (May 10 to October 10). The feeding value of the pasture is based on the difference between the cost of feed on pasture and on a dry ration.

The cow producing only 20 pounds of milk daily is maintained on pasture without supplementary feed. Her dry ration, off pasture, consists daily of 8 pounds of alfalfa hay, 35 pounds of corn silage, 1 pound of gluten feed, 0.5 pound of cottonseed meal, 0.5 pound of linseed meal, and 4½ pounds of corn and cob meal.

The cow producing daily 35 pounds of milk is fed in addition to pasture 8 pounds of corn and cob meal per day; dry ration (off pasture) 10 pounds of alfalfa hay, 35 pounds of corn silage, 6 pounds of corn and cob meal, 1½ pounds of wheat bran, 1 pound of gluten feed, 1 pound of linseed meal, and 0.5 pound of cottonseed meal per day.

The cow producing 50 pounds of milk per day is fed in addition to pasture 10½ pounds of corn and cob meal, 2 pounds of wheat bran, and 1 pound of gluten feed per day; dry ration (off pasture) 40 pounds of corn silage, 12 pounds of alfalfa hay, 6 pounds of corn and cob meal, 3 pounds of wheat bran, 2 pounds of gluten feed, 1 pound of cottonseed meal, and 1 pound of linseed meal per day.

The cost of feed is based on Pennsylvania prices from Janurary 1 to October 23, 1924. The prices per hundred weight are as follows: Cottonseed meal, $2.77; linseed meal, $2.38: gluten feed, $2.30; wheat bran, $1.73; corn and cob meal, $1.60; alfalfa hay, $.90; and corn silage, $.30.

TABLE 3.—*Computed value*[a] *of Kentucky bluegrass pasture furnishing 80 pounds of green grass per day for a period of 150 days.*[b]

Animal	Cost of feed for 150 days		
	Pasture	Dry ration off pasture	Difference in favor of pasture
1,200-pound cow, 20 pounds 3.5% milk per day..	——	$44.67	$44.67
1,200-pound cow, 35 pounds 3.5% milk per day..	$19.20	56.74	37.54
1,200-pound cow, 50 pounds 3.5% milk per day..	33.84	71.12	37.28
Average..............................	$17.68	$57.51	$39.83

[a] The sweet clover is not included in this or subsequent computations.

[b] The author acknowledges the valuable assistance of Prof. S. I. Bechdel in the computations of dairy rations used.

The figures in column 3 of Table 3 should not be confused with acre value, but represent the value of an area capable of producing 12,000 pounds of green grass throughout a period of 150 days. Table 4 shows the acre value and carrying capacity in relation to several fertilizer treatments. The carrying capacity is obtained by dividing 12,000, the number of pounds of green grass necessary for summer maintenance per head, by the yield in pounds per acre of green grass. The acre value is obtained by dividing the acres required to supply 12,000 pounds green grass into $39.83, which represents the average value of 12,000 pounds green pasture grass as shown in Table 3. The annual cost of fertilizer treatment shown in the second column of Table 4 is computed on the basis of Pennsylvania market prices for raw materials applied as home-mixed goods. Limestone is computed on the basis of 1 ton applied over a four-year period at a cost of $9.00.

TABLE 4.—*Computed acre value and carrying capacity of Kentucky bluegrass pastures in relation to fertilizer treatment.*

	Annual cost	Dekalb soil		Volusia soil		Westmoreland soil	
Soil treatment	of fertilizer and lime treatment	Acres required per cow	Annual acre value	Acres required per cow[a]	Annual acre value	Acres required per cow[a]	Annual acre value
Untreated.	——	——	——	40.67	$ .98	4.09	$ 9.73
Ca	$ 2.25	37.1	$ 1.08	2.54	15.68	1.83	21.76
CaP. . . .	4.04	1.72	23.15	1.96	20.32	1.24	32.12
CaPK. . . .	5.35	1.41	28.24	1.31	34.05	1.15	34.63
CaPKN. . .	10.56	1.01	39.43	0.89	44.75	0.82	48.58
CaMP. . . .	8.52	1.43	27.85	0.99	40.23	1.01	39.43

[a]Average of three checks.

The relative value of mineral fertilizers on the three soils is clearly shown in the above table, both in relation to increased acre value of pasture and decreased acreage required to maintain a dairy animal. The addition of acid phosphate to the limed land increased the acre value of Dekalb soil $22.07, of Volusia soil $4.64, and of Westmoreland soil $10.36. Potash applied to the land treated with limestone and acid phosphate increased the acre value of Dekalb soil $5.09, of Volusia soil $13.73, and of Westmoreland soil only $2.51. In like manner, nitrate of soda applied to the land treated with limestone, acid phosphate, and potash gave an increased acre value as follows: Dekalb soil, $11.19; Volusia soil, $10.70; and Westmoreland soil, $13.95. The value of the re-enforced manure is on an average $8.42 below that of the complete fertilizer. The use of a complete fertilizer on the limed land has increased the acre value on an average $31.41 as compared to $22.99 for manure. The acre value of summer pasture, where complete fertilizer was used, is $44.25 on an average of the three soils. This value may appear high due to the fact that current conception of the value of pasturage has been based on the present existing grazing land too often found on areas unsuited for the best development of economic grasses. The relative value of the several soil treatments in the production of Kentucky bluegrass may be emphasized by computing the acres required to maintain an average herd of 20 dairy cows for a period of 150 days. The summary in Table 5 shows the reduction in acreage brought about by the several treatments shown in Table 4.

TABLE 5.—*Computed acres of pasture required for maintenance of 20 cows for 150 days on three types of soil.*

Soil treatment	Dekalb soil	Volusia soil	Westmoreland soil
Ca	742.0	50.8	36.6
CaP	34.4	39.2	24.8
CaPK	28.2	26.2	23.0
CaPKN	20.2	17.8	16.4
CaMP	28.6	19.9	20.2

FEEDING VALUE OR DIGESTIBLE NUTRIENTS PRODUCED ON PASTURE AS COMPARED WITH A GRAIN ROTATION

Farmers have fully realized the economic importance of a grain rotation and have practiced a more or less standard soil treatment. At the same time, the grazing land has been neglected because of lack of knowledge concerning the possible feeding value of a highly developed pasture. It is of utmost importance, therefore, to emphasize the value of pasturage by showing the feeding value of the two systems of soil management when carried out on the same soils by using a similar system of fertilization. Table 6 shows the dry matter, digestible crude protein, and total digestible nutrients produced on an average of the three soils in a rotation of corn, oats, wheat, and grass (mixed clover and timothy) and on an equal pasturage acreage. From the known feeding value of the crops produced in such a rotation, the digestible nutrients are computed (1) on the basis of feeding the entire products including all straw, and (2) by feeding only the corn grain, stover, oats grain, and hay, the common practice in a dairy system. The value of corn grain is computed on the basis of the known value of corn and cob meal.

To the digestible crude protein supplied by bluegrass may be added 142 pounds produced by sweet clover, including also 776 pounds total digestible nutrients.

The pasture area produced, on an average for the three treatments, 1,403 pounds of digestible crude protein and 6,791 pounds of total digestible nutrients as compared with 562 and 6,730 pounds, respectively, produced in the grain rotation.

TABLE 6.—*Pounds of digestible nutrients produced on 4 acres of Kentucky bluegrass pasture as compared with an equal area in a four-year rotation of corn, oats, wheat, and hay, average of three soils.*

	Soil treatment		
	CaP	CaPK	CaPKN
Field weight of crops (dry matter), rotation	10,884	14,459	15,637
Field weight of crops (dry matter), pasture	9,228	11,052	15,968
Total digestible crude protein, rotation	449	603	635
Digestible crude protein (excluding wheat and straw)	362	484	500
Digestible crude protein produced on pasture	848	1,375	1,986
Total digestible nutrients produced by rotation	5,340	7,132	7,718
Total digestible nutrients (excluding wheat and straw)	3,566	4,837	4,993
Total digestible nutrients produced on pasture	4,932	5,907	8,535

LABOR ECONOMY OF PASTURE FEEDING

To produce a four-year rotation yielding 61 bushels of corn, 3,166 pounds stover, 33.3 bushels of oats, 28.3 bushels of wheat, and 3,200 pounds of hay on 4 acres requires 226 hours of man and horse labor at a cost of $59.61.[3] To maintain an established pasture would require annually on 4 acres not more than eight hours of man and horse labor for top-dressing mineral fertilizers and repairing fences at an annual cost of $2.80. If to this amount is added $2.40 per ton for grinding the grain necessary for cattle feed, the labor cost of the 4 acres of grain rotation would be approximately $67.00. On the basis of the above yields, 765 pounds of digestible crude protein and 8,407 pounds of total digestible nutrients would be produced, excluding the oats and wheat straw. On an average of the three soils, where complete fertilizers were used, the bluegrass pasture produced on 4 acres 1,986 pounds of crude digestible protein and 8,535 pounds of total digestible nutrients.

On the basis of the above figures, the labor cost necessary to produce 1 ton of digestible crude protein would be $178.22 for the rotation and $2.82 on the pasture. In like manner 1 ton of total digestible nutrients would involve a labor cost of $15.94 and $1.66, respectively. To produce 4 acres of ensilage corn yielding 37.2 tons involves a labor cost of $106.04. Such a yield would produce 744 pounds of digestible crude protein and 9,896 pounds of total digestible nutrients. The total digestible nutrients would be produced at a labor cost of $21.21 per ton as compared to $1.66 as shown for the pasture.

The above computations are presented to show the importance and economy of pasture feeding and not to discourage the use of grain rotations or ensilage feeding, both of which are vital factors in successful livestock production.

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[3] Summary of cost of production records in Lancaster County, Pa., 1921, by E. L. Moffitt and H. S. Sloat, Farm Management Extension, Pennsylvania State College.

ECONOMIC PASTURE FERTILIZATION

Table 7 and preceding tables furnish valuable data as a guide for determining the most economical fertilizer treatment for meadows and pastures. It has been shown that there is a distinctive difference in the response of cultivated crops and those in permanent sod to applications of soluble nitrogen. Phosphoric acid and potash, however, show practically the same values in the two cropping systems. Table 7 shows that nitrogen applied in addition to PK has no economic value in the grain rotation. However, the year nitrogen was applied to the PK treatment on the pasture, it gave 58% of the 100% increased yields attributed to P, K, and N. During the years following the fertilizer applications, phosphoric acid becomes the dominant factor, causing 75% of the total increased yields as compared to 21% for potash and only 4% for nitrogen. The CaPKN treatment gave yields 76% in excess of PK the year applied, but only a 2% increase over PK the following year. It becomes evident that nitrogen applied as nitrate of soda has no residual effect and should therefore be applied annually. Table 7 shows the relative value of P, K, and N in the production of bluegrass and crops in rotations.

TABLE 7.—*Percentage of increased yields attributed to P, K, and N in the production of Kentucky bluegrass and crops in a rotation system, computed on the basis of average yields on the three soils.*[a]

	Kentucky bluegrass			Grain rotation		
	P	K	N	P	K	N
Proportionate cost of treatment	21	16	63	21	16	63
Percentage increased yield, direct effect[b]	27	15	58	53	43	4
Percentage Increased yield, residual effect[c]	75	21	4	55	45	0

[a] P = CaP—Ca, K = CaPK—CaP, N = CaPKN—CaPK.

[b] Year fertilizers were applied.

[c] Second year residual effect.

SUMMARY AND CONCLUSIONS

1. Previous pasture improvement studies have dealt largely with an attempt to encourage the growth of existing grasses which vary in species and nutritive value in accordance with the particular soil conditions.

2. Such studies have been in the nature of pasture demonstrations where the sod has been top-dressed with lime, manure, and commercial fertilizers, sometimes re-seeded without any attempt to improve the physical properties of the soil by plowing.

3. Prior to the present studies little attention had been paid to the development of highly productive Kentucky bluegrass pastures on land equally as good as that now utilized for cultivated crops.

4. Lack of knowledge concerning the economic feeding value of highly productive Kentucky bluegrass pasture has been responsible for the general belief that the better phase of productive farm land should be used for rotation crops rather than for permanent pasture.

5. Immature Kentucky bluegrass excels all eastern pasture grasses, and also the legumes grown for hay, in nutritive value. It contains, in fact, 50% more digestible crude protein than found in the average of 44 other eastern pasture grasses.

6. The maximum growth of bluegrass was obtained on soils treated with limestone and a complete fertilizer.

7. The year the fertilizers were applied the CaP, CaPK, and CaPKN treatments show the following relative values for the production of bluegrass based on an average of the three soils expressed in percentage of increased yields: P, 27; K, 15; and N, 58. The second year residual effects were as follows. P, 75; K, 21; and N, 4.

8. On the years the fertilizers were applied, nitrogen added to the CaPK treated soil gave an average increased yield of 74%. Nitrogen, however, showed practically no beneficial residual effect the second year as compared to the PK treatment.

9. On an average nitrogen applied to the CaPK treatment gave the following increased yields: On Dekalb soil 40%, on Volusia soil 54%, and on Westmoreland soil 39%.

10. Nitrogen applied in nitrate of soda hastens the spring development of bluegrass, shortens the resting period during the hot summer months, and prolongs the late fall growth.

11. The yields on the CaPK treated plats are limited by the rate of nitrification (presence of soluble nitrates) and not by the total amount of nitrogen present. Soluble nitrogen should, therefore, be applied annually.

12. The computed carrying capacity (acres per cow) is based on 80 pounds of green grass per day for 150 days. The computed value is based on the difference in cost of feeding dairy cattle on and off pasture for a period of 150 days.

13. The average computed acre value of the pasture resulting from the several treatments is as follows: No treatment, $3.57; CaP, $25.20; CaPK, $32.31; CaPKN, $40.92; and CaMP, $35.84.

14. Labor economy of pasture feeding is emphasized by the fact that to produce 1 ton of digestible crude protein in grain rotation

involves a labor cost of approximately $178.00 as compared to $2.82 on pasture.

15. Four acres of ensilage corn (Lancaster County) yielding 37.2 tons would produce 744 pounds digestible crude protein and 9,896 pounds total digestible nutrients at a labor cost of $106.04. The labor cost per ton of total digestible nutrients would be $21.21 as compared to $.66 on pasture.

16. At least 80% of the 4,000,000 acres of so-called Pennsylvania grazing land could be more economically utilized for refcrestation. One-half of the remaining area (400,000 acres) in highly developed Kentucky bluegrass pasture would supply sufficient protein for the summer production of milk (1,900,000 gallons, estimated) and also would provide for the other grazing animals. The remaining area could be utilized to advantage for permanent orchards.

17. Highly developed dairy cows or the heavier types of beef cattle are not ranging animals and should secure their food on limited areas. A pasture supplying an abundance of nutritious feed enables the animal to utilize the grass to better advantage for milk or beef production by reducing the proportion of nutrients required for body maintenance. Such a pasture has been shown also to be more economical on the basis of money expended for fertilizing materials.

18. Every stockman should realize the important fact that direct sunshine is of vital importance to the welfare of his animals. Science has proved that direct sunlight greatly stimulates mineral metabolism (80 pounds of fresh Kentucky bluegrass contains 32 grams of calcium and 25 grams of phosphorus). Dairy cows in open pasture are more resistant to disease and their milk has a higher vitamin content than that of cows kept under shelter.

CAUSES OF INCREASED YIELDS OF SUGAR BEETS FOLLOWING APPLICATIONS OF BARNYARD MANURE[1]

D. W. PITTMAN AND JOHN F. FONDER[2]

The increased yield of sugar beets following the application of barnyard manure is the most outstanding result secured on the Greenville Farm of the Utah Experiment Station near Logan.

Table 1, which is an average of five years' results, shows that for this particular soil and climate manure is even more important than irrigation in the production of sugar beets. This is in spite of the fact that the average annual precipitation is only 16.31 inches and the annual evaporation from a free-water surface is 33.5 inches, so that irrigation or special dry-farming methods are necessary for the successful production of farm crops.

TABLE 1.—*Yield of sugar beets without irrigation contrasted to yield without manure, five-year average.*

Treatment		Yield in tons per acre
Manuring	Irrigation	
Manure	Optimum	21 6
Manure	None	10.3
None	Optimum	5.1

The purpose of this experiment was to determine, if possible, something as to the reason for these outstanding results. There are many reasons customarily given for the beneficial effects of barnyard manure on crops, such as the plant-food added (especially nitrogen and potassium), the organic matter added, the vigorous beneficial bacteria added, the improved physical condition of the soil due to the addition of organic matter, the improved bacteriological condition due to these other factors, and combinations of these factors. A search of the literature revealed surprisingly little that would tend to show which of these reasons was the more important under conditions of a highly calcareous, semi-arid, perfectly drained loam soil under irrigation.

A knowledge as to which of these are the more important factors would aid in the study of methods of preserving manure and in a search for a satisfactory substitute.

Eleven experimental plats were selected which are typical of the sugar-beet plats with and without manure on the station farm.

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[1] Contribution from the Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Received for publication December 2, 1926.

[2] Associate Agronomist and graduate student, respectively. This paper contains a part of the thesis presented by Mr. Fonder for the degree of Master of Arts in Agriculture.

The soil of these plats was carefully sampled to a depth of 8 inches and examined for some of its physical, chemical, and biological properties to determine which of these was more nearly correlated with the yield of sugar beets produced. It was impossible to secure this many plats of identical treatment and previous history, so the plats have been grouped according to their proximity and previous history.

The apparent specific gravity, as determined in the field shortly before harvest, was used as an index of the physical condition of the soil because it shows the actual tilth of the soil as it lays. Since the tillage and irrigation of all of the plats were identical, it was thought that the different manuring treatments should determine largely the difference in tilth. A 3-inch drive tube was driven 8 inches into the soil at five places symmetrically distributed on the plats, and the soil removed, dried, and weighed to determine the apparent specific gravity of the surface. The samples thus secured were composited and, except for the nitrate and nitrification tests, used in the subsequent analyses.

Chemical tests were made for organic matter, total nitrogen, and nitric nitrogen. as these would seem to be the properties most influenced. A complete chemical analysis of a soil sample from this same field made by Widtsoe[3] shows the soil to contain 0.41% P_2O_5 and 0.67% K_2O, so there would seem to be no shortage of these elements.

The organic matter was estimated by determining the total carbon with a Parr bomb, subtracting the carbonate carbon, and multiplying by Wolf's factor 1.732. The nitrogen was determined by the modified Kjeldahl method, and the nitrates by the phenoldisulfonic colorimetric method. Since the nitrate varies with the season, three different determinations were made. The tests were made just before irrigation or following a period of evaporation when the nitrates would be accumulated in the surface soil.

The rate of nitrification of ammonia by the samples taken just before harvest was used as an index of the bacteriological activity of the soil.

The figures given represent parts per million of nitric nitrogen formed from ammonium sulfate solution added to the soil under certain standard conditions. The results of all these determinations are shown in Table 2.

The treatment of the plats is as follows:

Plat 1. Four-year rotation of potatoes, beets, wheat, and clover

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[3] WIDSTOE, J. A. The movement of water in irrigated soils. Utah Agr. Exp. Sta. Bul. 115:202. 1912.

TABLE 2.—*Effect of manure on various soil properties and the yield of sugar beets on plats receiving different manurial treatments (surface soil).*

	Plat No.											
	1	2	3	4	5	6	7	8	9	3	10	11
Manure, tons per acre	0	10/4	0	5	15	40	0	10	30	0	20/2	20
Yield, tons per acre	2.8	13.4	7.2	25.3	30.4	30.5	7.8	23.6	23.7	7.2	18.4	26.2
Apparent specific gravity	1.09	1.23	1.29	1.24	0.99	1.09	1.29	1.2	1.1	1.29	0.89	0.9
Organic matter, %	3.48	2.93	1.56	2.16	2.93	4.55	1.86	3.31	3.04	1.56	0.98	2.16
Total nitrogen, %	0.18	0.13	0.16	0.23	0.27	0.33	0.14	0.16	0.23	0.16	0.13	0.16
Nitric nitrogen (April 19), %	5	9	5	11	13	21	6	13	14	5	7	13
Nitric nitrogen (June 11), %	10	17	33	45	50	45	22	50	40	33	26	33
Nitric nitrogen (October 25), %	17	6	6	4	17	48	15	13	31	6	18	14
Nitrification (October), p. p. m	218	255	167	273	218	117	216	250	220	167	226	274

since 1922, with no manure. Soil previously exhausted by 10 years' continuous grain without manure.

Plat 2. Same as Plat 1, but 10 tons of manure applied before potato crop (twice since 1922).

Plat 3. Continuous sugar beets with no manure since 1916; never manured.

Plat 4. Continuous sugar beets since 1918; 5 tons manure per acre every year since 1910; never manured before.

Plat 5. Same as Plat 4, except 15 tons of manure per acre each year.

Plat 6. Same as Plat 4, except 40 tons of manure per acre each year.

Plat 7. Continuous sugar beets, with no manure since 1916; never manured.

Plat 8. Same as Plat 7, except 10 tons manure per acre each year since 1916.

Plat 9. Same as Plat 7, except 30 tons manure per acre each year since 1916.

Plat 10. Continuous sugar beets since 1916; 20 tons manure per acre, each alternate year since 1922; never before manured.

Plat 11. Same as Plat 10, except 20 tons manure per acre each year since 1922.

The coefficients of correlation[4] are as follows:

Yield to manure	r = 0.77	± 0.083
Yield to total nitrogen	r = 0.67	± 0.112
Yield to organic matter	r = 0.44	± 0.164
Yield to apparent specific gravity	r = —0.49	± 0.155
Yield to nitric nitrogen in April	r = 0.73	± 0.095
Yield to nitric nitrogen in June	r = 0.85	± 0.057
Yield to nitric nitrogen in October	r = 0.42	± 0.167
Yield to nitrification in October	r = 0.08	± 0.202
Yield to carbon-nitrogen ratio	r = 0.01	± 0.203
Manure to organic matter	r = 0.64	± 0.120
Manure to total nitrogen	r = 0.75	± 0.089
Manure to nitric nitrogen in April	r = 0.60	± 0.130
Manure to nitric nitrogen in June	r = 0.65	± 0.117
Manure to nitric nitrogen in October	r = 0.87	± 0.050

These figures show the most appreciable correlation between the yield and nitric nitrogen in the spring and summer, and yield and total nitrogen with low correlation between yield and organic matter or apparent specific gravity, and practically none between yield and fall-nitrifying power or carbon-nitrogen ratio. A casual inspection of Table 2 bears out these observations. These results thus seem to indicate that on this soil farm manure is of value to sugar beets not so much for its organic matter or for its physical or bacteriological effect on the soil as for the nitrogen it contains.

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[4] $r_{xy} = \left(\frac{\Sigma\,(d\ d_y)}{n}\right)\left(\frac{1}{\sigma_x\,\sigma_y}\right) \qquad \sigma = \sqrt{\frac{\Sigma\,(f\ d^2)}{n}}$

Formulae given in "Genetics in Relation to Agriculture," by Babcock and Clawson. McGraw-Hill Co., New York. Pages 41 and 54.

INFLUENCE OF FERTILIZER TREATMENTS ON STAND OR GERMINATION OF COTTON[1]

G. W. MUSGRAVE AND DANA G. COE[2]

In practice fertilizer injury to various crops has been frequently noted, more often being observed under conditions of a deficient moisture supply than when a normal or surplus amount is available. Truog, et al (4),[3] in reviewing the literature on the effect of fertilizers upon germination, state that, "A considerable number of investigations have been made on the effect of fertilizers and salts upon germination, but comparatively few in which the method of application, moisture content of the soil, and the soil class have been considered." It might be added that there is a great dearth of such information, particularly with reference to cotton to which crop there is annually applied a greater sum total of commercial fertilizers than to any other.

Without attempting to make a complete review of the literature at this time, some of the more important results may be briefly indicated. Hutcheson and Wolfe (3) found that, "Air-slaked lime, muriate of potash, and nitrate of soda reduced germination on silt loam soil, while all of the above and sulfate of potash reduced the germination on sandy loam. Acid phosphate did not appreciably reduce the stand. The crops used were corn, wheat, rye, oats, soy beans, alfalfa, red clover, timothy, and red top."

Hicks (2) concludes that when muriate of potash and sodium nitrate are used as fertilizer in strengths of 1% or more, they are very detrimental to the germination of seeds. Fertilizers composed of phosphoric acid or lime (from powdered oyster shells) are much less injurious.

Harris (1) in his study of the effect of alkali salts in soils on crops says that the "Toxicity of soluble salts in the soil was found to be in the following order: Sodium chlorid, calcium chlorid, potassium chlorid, sodium nitrate, magnesium chlorid, potassium nitrate, magnesium nitrate, sodium carbonate, potassium carbonate, sodium sulfate, potassium sulfate, and magnesium sulfate."

The anion or acid radical and not the cation or basic radical is said to determine the toxicity of these salts in the soil.

Truog, et al (4), show that the degree of injury to germination is lessened under conditions of ample moisture, finer textured soils, or reduced concentrations of salts about the seed.

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[1] Contribution from the American Cyanamid Co., 535 Fifth Ave., New York City. Received for publication December 11, 1926.

[2] Agronomist and Regional Agriculturist, respectively.

[3] Reference by number is to "Literature Cited," p. 180.

In order to determine whether the above effects are applicable to cotton and with a view to developing the basic facts upon which a fertilizer practice of the highest degree of efficiency may be worked out for the cotton crop, an extensive investigational program has been inaugurated during the present year. It is the purpose of the present paper to report the phases of this work having general interest.

The experiments from which the following results were derived consist (a) of a 20-acre field in North Carolina[4] which is subdivided into 1/40 acre plats and which provides six replications of each treatment. It is located upon a terrace formation of the Coastal Plain, the soil of which has been identified (in the absence of a published soil survey of the region) as Cahaba fine sandy loam and Cahaba loamy fine sand. (b) A total of 30 acres in Oklahoma, of which 20 acres have a similar plat arrangement. The remaining 10 acres have a different type of arrangement, the latter permitting comparisons in series of seven plats of each method of application, as indicated subsequently. The soil here is a Kirkland fine sandy loam. Both areas were chosen for the uniformity of soil upon which the experiments were to be placed. The Oklahoma soil, however, contains a larger proportion of finer soil particles and has a higher colloidal content.

The seed used in both sets of experiments was pedigreed and selected for high germination.

The rainfall records were obtained from rain gauges placed upon

TABLE 1.—*Rainfall at North Carolina experimental field.*

April		May		June	
Date	Inches	Date	Inches	Date	Inches
3	0.10	3	0.30	4	0.11
8	0.23	9	0.18	5	0.62
11	0.31	10	0.37	11	0.14
13	1.21	13	0.05	12	0.15
15	0.07	15	0.13	19	0.23
18	0.10	16	0.16	20	0.24
23	0.74	28	0.11	24	0.49
		31	0.10	27	0.51
Total	2.76		1.40		2.49

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[4] Acknowledgment is made to W. H. Rankin, formerly Agronomist of the North Carolina Agricultural Experiment Station, and subsequently Regional Agriculturist of the American Cyanamid Co., for the results reported from the North Carolina field.

each field. These show in the North Carolina experiment a total of 1.57 inches for the period covering the planting date (May 12) to the final stand count (June 18) as given in Table 1.

The total precipitation before and during the germination period was below normal, and accordingly it may be assumed that any inhibition of germination due to fertilizer treatments was more marked than would be the case under a heavier rainfall. Concentration of a salt solution of considerable density about and near the seed would be quite effective, of course, in reducing the germination of the seed. The final average stand obtained on the check plats, however, was approximately normal and sufficient to produce a good crop of cotton.

In the Oklahoma experiments also, somewhat deficient rainfall prevailed during the early part of the present year (Table 2), but good stands of cotton were obtained where such were not influenced by the method of application.

TABLE 2.—*Rainfall at Oklahoma experimental field.*

April		May		June		July	
Date	Inches	Date	Inches	Date	Inches	Date	Inches
9	0.63	2	0.07	3	1.51	7	0.30
10	1.71	6	0.35	4	0.10	10	3.76
22	0.15	18	0.07	17	1.17	13	3.10
		30	1.17	18	0.32	22	1.20
				21	0.55	24	0.45
				24	0.05	25	3.52
Total	2.49		1.66		3.70		12.33

EFFECT OF NITROGEN SALTS ON STAND OF COTTON

The effect of soluble nitrogen salts from the usual sources and in a complete fertilizer in comparison with phosphoric acid and potash and with no fertilizer is indicated in Table 3, showing that the application of the nitrogen salts and also the application of phosphorus and potassium salts have inhibited germination.

The nitrogen plats are averages for six fertilizer mixtures in which

TABLE 3.—*Effect of nitrogen salts on stand of cotton, North Carolina field.*

Fertilizer treatment	Rate in pounds per acre	Number of 1/40 acre plats averaged	Total length of rows counted, feet	Mean stand per 100 feet
N	20	36	3,600	119.0 ±6.10
P_2O_5	50			
K_2O	20			
No N	—	6	600	147.17±9.41
P_2O_5	50			
K_2O	20			
None	—	6	600	160.17±9.73

the nitrogen was supplied from the several conventional sources and in several combinations, all of which produced similar effects upon the stand. The fertilizer was applied at time of planting and in the row avoiding contact with the seed, making the application as nearly as possible in the customary manner. After preparing the beds, they were opened in the usual manner and the fertilizer applied by hand. Approximately 2 inches of soil were then thrown over the fertilizer by the use of a light plow and the seed then planted with a cotton planter leaving the relative positions of seed and fertilizer as nearly as possible as follows: Seed 1 inch beneath surface of bed, fertilizer 3 inches beneath surface of bed and approximately 1 inch above the bottom of the water furrow.

EFFECT OF INCREASING QUANTITIES OF NITROGEN ON STAND OF COTTON

In another portion of the same experimental field there was a comparison of increasing quantities of nitrogen from several sources applied at several intervals before planting. The same basic application of phosphate and potash was made, and the fertilizer was applied in the manner described above. One may compare this series with respect particularly to the rate of application of nitrogen, since the sources of nitrogen and methods of application were the same for each rate of application. These comparisons are given in Table 4 in which the effects of increasing quantities of soluble salts, even though applied in the conventional manner, are clearly evident.

TABLE 4.—*Effect of increasing quantities of nitrogen upon stand of cotton in North Carolina field.*

Pounds of nitrogen applied per acre	Total plants counted in 90 plats[a]	Mean stand per 100 feet
20	12,542	139.35±4.31
30	11,017	122.41±3.81
40	10,549	117.21±5.23
50	9,447	104.96±3.71

[a] 100 feet of row were counted in each plat.

EFFECT OF TIME OF APPLICATION OF NITROGEN UPON STAND OF COTTON

In the above experiment the nitrogen was applied in four series of varying intervals before planting, namely, at one, two, and three weeks before the planting date and at planting. A comparison of the stand counts from this series is of interest and the results (Table 5) show significantly better stands from the applications made prior to planting.

It appears that under the conditions of these experiments the best stand was obtained from the applications of nitrogen made one week

TABLE 5.—*Time of application of nitrogen and stand of cotton in North Carolina field.*

Nitrogen applied	Total plants counted in 72 plats[a]	Mean stand per 100 feet
3 weeks before planting....	8,751	121.5±4.65
2 weeks before planting....	9,342	129.7±3.91
1 week before planting.....	10,725	148.9±6.61
At planting..............	7,544	104.8±3.84

[a] 100 feet of row were counted in each plat.

before planting and that the stand decreased with applications made the second week and third week, but was lowest from the treatment made at the time of planting. Whether the differences between the one, two, and three week applications can be the result of seed stimulation is not known. Owing to the systematic replication of the plats, however, and the general method of handling the work, it can scarcely be due to chance variation. It seems clear that the applications before planting have resulted in considerably better stands than applications at planting time.

No marked differences in stand from the various nitrogen sources resulted from the applications made in the manner followed in this test. The consistency of the data in this respect is indicated in Table 4, where the probable error of the mean derived from all nitrogen sources is low, actually less than 5%.

EFFECT OF FERTILIZER MATERIALS OTHER THAN NITROGEN UPON STAND

The effect of phosphorus and potash, particularly the latter, upon the germination of cotton is indicated in another series of plats. Using the same fertilizer ratio (10–4–4)[b] and the same rate per acre (500 pounds) adopted as the basic treatments throughout, a comparison is possible between applications in which all of the fertilizer materials were applied one week before planting and applications in which the nitrogen only was applied one week before planting, the phosphoric acid and potash being applied at the planting date. The effect of delaying the application of acid phosphate and muriate of potash by one week has been to reduce the stand about 20% under the conditions of this test (Table 6).

TABLE 6.—*Effect of phosphate and potash on stand of cotton in North Carolina field.*

Treatment	Total plants counted in 48 plats[a]	Mean stand per 100 feet
P and K at planting N one week in advance	5,826	121.4±5.53
All materials one week in advance of planting	7,256	151.2±6.91

[a] 100 feet of row were counted in each plat.

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[b] Phosphorus pentoxid, nitrogen, and potash.

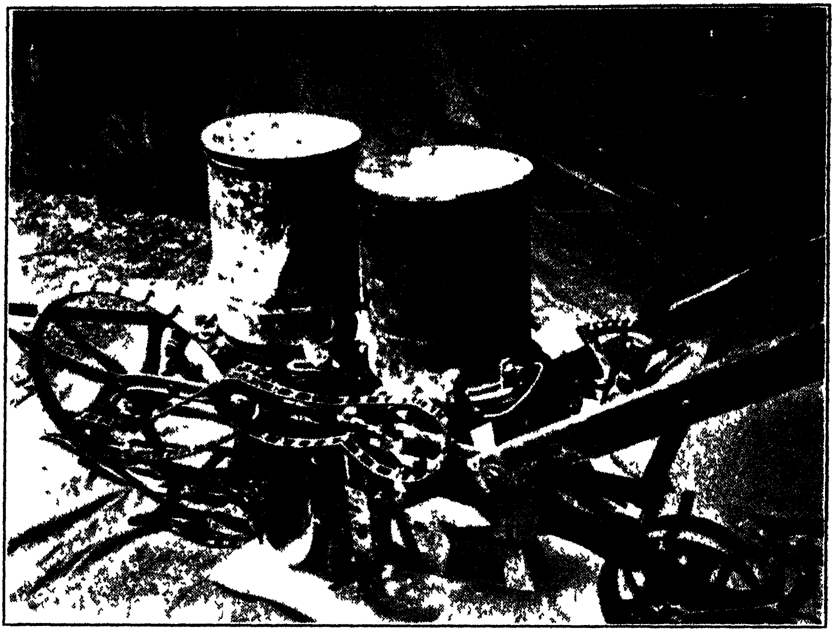

FIG. 1.—Planter and distributor modified by local blacksmith and used in Oklahoma work Adjustment here is for a fertilizer application on either side of the seed row Other adjustments are possible.

The above data on the effect of phosphate and potash are substantiated largely by experiments on the Oklahoma field where two rates of application were made with the results shown in Table 7.

TABLE 7.—*Effect of phosphate and potash on stand of cotton in Oklahoma field.*

Fertilizer Rate per acre in pounds	Formula	Mean stand from 150-foot row[a]	Comparison of	Mean difference	S. D.	Odds[b]
500	12-4-4	260.7				
500	12-0-4	266.7	12-4-4 with 12-0-4	6.0	51.2	1.5 to 1
500	12-0-0	353.2	12-0-4 with 12-0-0	86.6	75.1	63.5 to 1
			12-4-4 with 12-0-0	92.6	72.6	95.7 to 1
250	12-4-4	308.1				
250	12-0-4	351.3	12-4-4 with 12-0-4	43.2	87.0	6.4 to 1
250	12-0-0	489.0	12-0-4 with 12-0-0	137.7	94.4	163.0 to 1
			12-4-4 with 12-0-0	180.9	84.6	1832.0 to 1

Mean of seven checks (no fertilizer), 475.7±7.81.

[a] Averages of seven methods of application for each fertilizer treatment as given in Tables 8 and 9.

[b] Odds computed by Love's modification of Student's method. (Jour. Amer. Soc. Agron., 16:68–73. 1924.)

It seems clear that in both the 250- and 500-pound applications that the 12-4-4 fertilizer has produced significantly lower stands than the 12-0-0. To a lesser extent, also, the 12-0-4 has produced lower stands than the 12-0-0. In so far as the 12-0-4 and 12-4-4 comparisons are concerned, the data show no conclusive differences in these cases. This may be due to the fewer number of replications in this experiment (seven), or possibly to the somewhat higher colloidal content of the Oklahoma soil than occurs in the North Carolina soil. Comparing the 12-0-0 plat treatments with the check plats, there appears to be no significant difference where 250 pounds only were applied. In the 500-pound application, however, the phosphate has depressed the mean stand from 475 on the check plats to 353 on the phosphate plats.

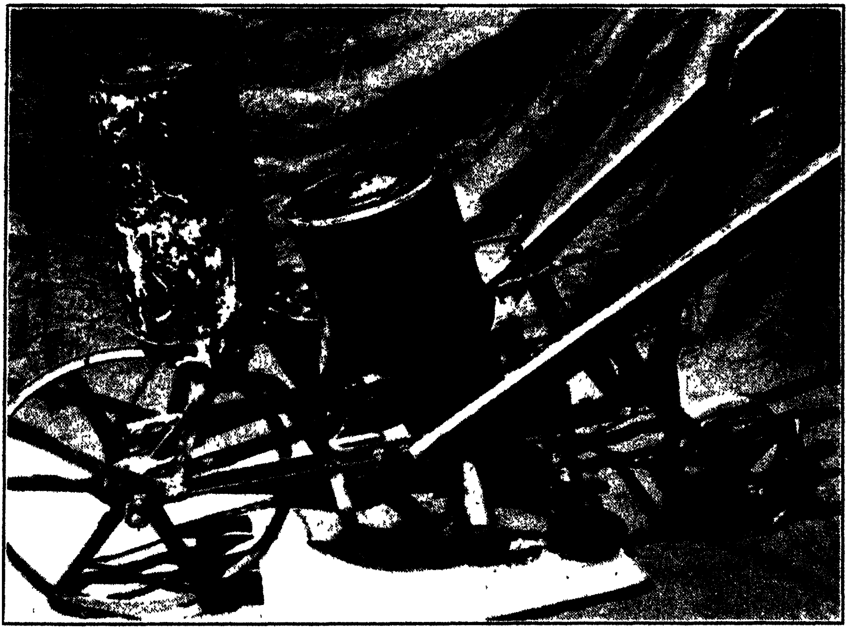

FIG. 2.—Another type of planter and distributor on which a flexible fertilizer spout has been substituted and the shoe moved forward permitting in its present adjustment direct contact of seed and fertilizer.

REDUCTION OF INJURY BY MODIFIED METHOD OF APPLICATION

That the depressing effect upon germination which is indicated in the above tables may be largely overcome by a modification of the usual method of application is clearly shown by a comparison of the stands resulting from seven methods of application given in Tables 8 and 9.

TABLE 8.—*Effect of different methods of applying fertilizer (500 pounds per acre) upon stand of cotton in Oklahoma field.*[a]

Method of application	Number of plants in final germination count[b] Fertilizer formula 12–4–4 A	 12–4–4 B	 12–4–4 C	 12–0–4	 16% acid phosphate	 Total	 Mean stand
Direct contact	29	25	81	82	279	496	99.2
Below 1 inch, narrow . . .	187	96	154	120	190	747	149.4
Below 2 inches, narrow. . . .	60	147	140	150	279	776	155.2
Below 1 inch, wide.	62	235	170	118	287	872	174.4
Above seed. . .	231	511	441	501	483	2,167	433.4
Both sides. . .	466	459	459	432	484	2,300	460.0
One side	498	495	528	464	471	2,456	491.2
Totals.	1,533	1,968	1,973	1,867	2,473	9,814	280.4
Averages.	219.0	281.1	281.9	266.7	353.3		

Check plats
(unfertilized) 423 489 467 465 483 478 525 3,330 475.7 ±7.81

[a] The applications described as "below 1 inch, narrow" were applications 1 inch below the seed and in a narrow band, i. e., the fertilizer band was approximately 1½ inches in width. The application "below 2 inches, narrow" was made 2 inches beneath the seed and in a band of the same width. The application "below 1 inch, wide" was made 1 inch below the seed and in a band approximately 3 inches in width. The "above seed" application was approximately 1 inch above the seed. The "both sides" application placed the fertilizer about 1 inch on either side of the seed and at the same level, with which the application "one side" was identical, excepting that all the fertilizer was on one side of the seed rather than on both sides.

[b] 150 feet of row were counted on each plat.

TABLE 9.—*Effect of different methods of applying fertilizer (250 pounds per acre) upon stand of cotton in Oklahoma field.*

Method of application	Number of plants in final germination count Fertilizer formula 12–4–4 A	 12–4–4 B	 12–4–4 C	 12–0–4	 16% acid phosphate	 Total	 Mean stand
Direct contact	29	54	132	225	422	862	172.4
Below 1 inch, narrow . .	138	179	189	102	310	918	183.6
Below 2 inches, narrow. . .	181	285	319	227	438	1,450	290.0
Below 1 inch, wide	158	366	273	226	482	1,505	301.0
Above seed. .	336	403	409	549	591	2,288	457.6
One side.	478	578	445	557	578	2,636	527.2
Both sides. . .	445	564	509	573	602	2,693	538.6
Totals.	1,765	2,429	2,276	2,459	3,423	12,352	352.9
Averages. . . .	252	347	325	351	489		

Check plats
(unfertilized) 423 489 467 465 483 478 525 3,330 475.7 ±7.81

These latter plats were from machine plantings where, by the use of several adjustments of the furrow openers and delivery pipes, etc., provided by a local blacksmith, the applications were made in a manner closely simulated by large scale field operations. (See Figs. 1 and 2.)

These stand counts are the last of a series of counts which were made following several light showers occurring after planting, the final one being taken on July 16. Planting was on June 22. The plats consisted of three rows, each 100 feet long, and were without replication, excepting for the checks. The stands resulting from the several methods of application are given in Table 8.

A comparison of the average results from the several methods of application shows that both the direct contact application and the "below 1 inch, narrow" application produced decidedly inferior stands. An increase in depth of the fertilizer band or an increase in its width of distribution gave somewhat improved stands, but nevertheless stands which were inferior to the check or no treatment plats. On the other hand, the "above," "both sides," and "one side" applications appear to have produced stands fully equal to the check plats. However, certain obvious disadvantages of both the "above" and the "below" applications should not be overlooked. The "above" application leaves the fertilizer out of the root zone and normally in dry soil; it is difficult to accomplish in cotton planting because of the usual shallow planting; contact with the seed is difficult to avoid; and the narrow fertilizer band above the seed may cause injury to the penetrating seedlings. Likewise, "below" applications are attended with certain disadvantages. Capillary movement of moisture upward may be interfered with, both because of the broken soil structure resulting from the fertilizer application and because the interposed layer of salts may itself tend to retain moisture, particularly under rather dry conditions. A compact seedbed is especially important with cotton. Such applications are further attended with the mechanical difficulty of attaining to any appreciable degree a *wide* dispersion of salts at the proper depth, a practice which doubtless would be helpful in obviating any fertilizer injury.

One may speculate upon the possible effects of abnormal rainfall upon the relative stands from the "above" and "below" applications. It is logical to suppose that under higher rainfall the "above" applications may be carried down to contact with the seed. On the other hand, it may be logical to assume that under certain conditions of deficient rainfall the capillary movement of soil moisture would be largely upwards establishing what is in effect a contact application, or at least a high concentration of salts adjacent to the seed from the "below" applications with consequent unfavorable results. Regardless of abnormalities of moisture conditions, however, there seems to be less likelihood of injury occurring where "side" applications are made, since the lateral diffusion is probably slight and neither upward nor downward movement of soil moisture will establish contact with seed. Further work under controlled moisture conditions is being done to settle these points more definitely.

CONCLUSIONS

Certain relationships between fertilizer applications and resulting stands (or germination) of cotton are shown. Applications made below the seed along the row, a method commonly followed in practice, have inhibited the germination of cotton. The effect appears to be more pronounced from nitrogen and potassium salts than from phosphorus. The inhibition increased with increasing quantities of nitrogen from all sources and is more marked with applications at time of planting than with applications made prior to planting.

Comparing different methods of locating the fertilizer with reference to the seed, there are several which, under the conditions of these experiments, have given results, that are fully equal to the checks. Direct contact applications are inferior and so also are concentrations of fertilizers immediately below the seed. Especially worthy of consideration (from the viewpoint of seed germination) are applications at the side of the seed row, within the cotton bed, and at approximately the same level as the seed.

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WHEAT GERMINATION STUDIES WITH PARTICULAR REFERENCE TO TEMPERATURE AND MOISTURE RELATIONSHIPS[1]

HAROLD K. WILSON AND CHARLES F. HOTTES[2]

INTRODUCTION

The purpose of this investigation was to study the temperature and moisture relationships of different varieties of wheat (*Triticum vulgare*) with the hope of leading to a better understanding of the germination phenomena of this crop. There is reason to believe that much of the early literature on germination is not altogether satisfactory because many of the studies were incomplete by reason of an insufficient range of tests. Through a sufficiently wide range of tests it was the aim of the present studies to arrive at definite results that would form a basis for recommendations valuable for use in seed testing laboratories and for further studies of germination.

Moisture as well as temperature is essential for germination and it is natural that these two factors should be considered concomitantly.

MATERIALS AND METHODS

Six varieties of wheat were used in the investigation reported. With the exception of Worlds Champion and Illinois No. 1, effort was made to secure representative varieties of the three most important market classes of wheat, hard red spring, soft red winter, and hard red winter. The spring varieties used were Marquis and Illinois No. 1. The latter wheat was increased by the Illinois Agricultural Experiment Station from a sample of seed obtained from a Champaign County, Illinois, farmer in 1917. Red Cross, synonymous with Red May, according to Clark, Martin, and Ball (5)[3], and Mediterranean were chosen as representatives of the soft red winter class; while Turkey Red and Worlds Champion were selected from the hard red winter group. Worlds Champion is a selection from Turkey Red obtained by the Illinois Agricultural Experiment Station in 1915 from the L. A. Olds Seed Company, Madison, Wisconsin.

To make a study of climatic influences on the germination of wheat, samples of some varieties were secured from other states as follows: Turkey Red from Kansas and Indiana; Marquis from North Dakota; Rocky Mountain, a synonym (5) for Mediterranean, from Virginia, and T. S. 3289-2, a pure-line selection of Mediterranean from Texas.

[1] Contribution from the Department of Agronomy and the Division of Plant Physiology, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Station. Received for publication December 13, 1926.

[2] Graduate student in Agronomy and Consulting Plant Physiologist, respectively.

[3] Reference by number is to "Literature Cited," p. 189.

TEMPERATURE STUDIES

The temperature studies were made with the wheats arranged on 6 cm. square, plaster of paris blocks placed in water in metal germinating pan chambers. The blocks were cross-ruled with lines about three-fourths of a centimeter apart. Ten lines each way provided space for 100 seeds at the intersections. One germinating chamber was placed in each of four automatically controlled temperature cases held at constant temperatures of 10°, 15°, 20°, and 30°C, respectively.

As each chamber contained space for six blocks carrying 100 seeds each and as six varieties of wheat were used, it was possible to germinate all at one time under uniform conditions. Each test was duplicated, giving an average of two lots of 100 seeds each for use in determining the final germination percentages. In a few cases where apparent deviations from the expected results were obtained, as in the case of Worlds Champion wheat at 30°, the tests were replicated as often as four times.

In reading the germination tests it seemed best to consider a kernel of wheat as having germinated only when it possessed both a root and a shoot, for it did not seem justifiable to consider that the appearance of radicle or plumule alone constituted germination. Accordingly, in the present studies, the time of germination was taken as the period required for the seed to produce a normal radicle and plumule.

Abbe (1) cites de Candolle as follows, "De Candolle takes as the moment of germination that when, the spermoderm being broken, the radicle begins to issue forth " Oftentimes wheat will produce a radicle but no plumule and vice versa. Under such conditions growth soon ceases and germination is not considered as having taken place.

Initial germination, as used in this paper, refers to the period when the first seeds germinated. Complete germination signifies the stage

TABLE 1.—*Percentage germination of Illinois wheat varieties and the percentage of moldy kernels failing to germinate at the temperatures indicated.*

Variety	Percentage germination at 10°	15°	20°	30°	All temperatures	Percentage moldy kernels at 10°	15°	20°	30°	All temperatures
Illinois No. 1.	81	87	78	70	79	6	6	18	30	15
Marquis ...	90	89	76	55	78	4	5	19	45	18
Red Cross....	90	93	90	56	82	3	4	8	42	14
Mediterranean	97	97	90	62	87	0	3	10	32	12
Turkey Red..	94	92	91	50	82	1	2	6	43	13
Worlds Champion..	95	92	89	21	74	2	3	9	48	16
All varieties .	91	92	86	52	80	3	4	12	40	15

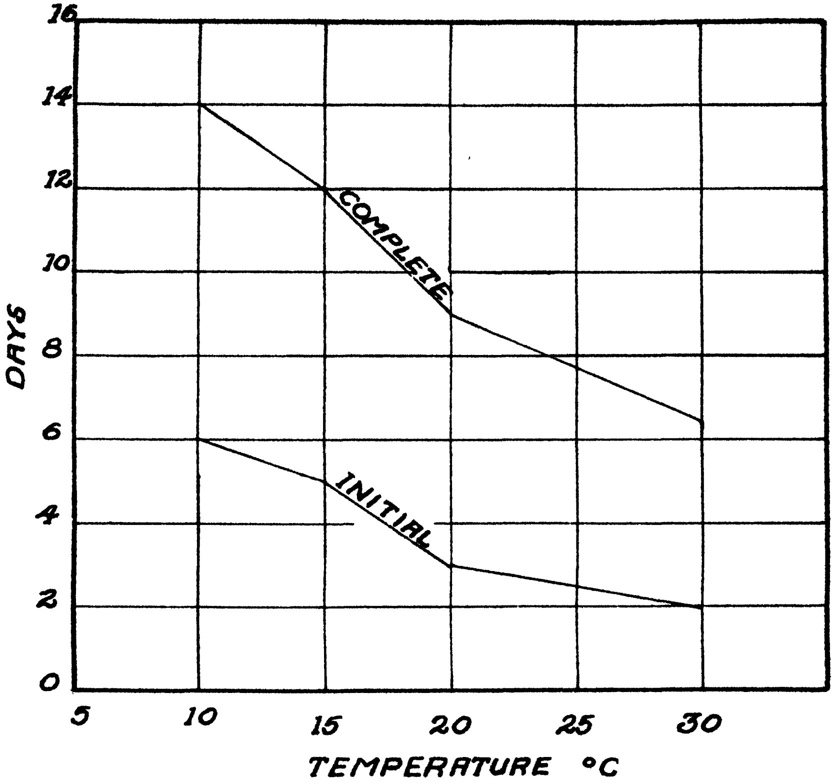

FIG. 1.—Effect of temperature on the number of days required for initial germination and for complete germination.

reached when there was no further increase in the number of seeds germinating.

The results secured in these studies are decidedly at variance with the reports of some of the earlier investigators, but are quite comparable with the results obtained by more recent investigators. Table 1 gives the germination at different temperatures.

It is often stated that the processes of growth conform in a general way to van't Hoff's law for chemical reactions, namely, that with an increase in temperature of 10°C there is a doubling or trebling in the rate of reaction. Czapek (8) states that the chemical reactions in plants strictly follow the same law. In the case of each wheat variety studied the initial germination appeared to follow the van't Hoff law in a general way. Average results showed that initial germination occurred as indicated in Table 2.

The results given in Table 2 are illustrated graphically in Fig. 1, and they indicate that the time required for complete germination

TABLE 2.—*Number of days required for initial germination and for complete germination of all wheat varieties studied.*

Temperature	Days for initial germination	Days for complete germination
10°C.	6.0	14.0
15°C.	5.0	12.0
20°C.	3.0	9.0
30°C.	2.0	6.5

does not follow the regular curve given by the initial rate, although the trend is similar. This was to be expected as various modifying influences such as moisture, molds, and varietal differences have more influence on the time of complete germination than on the time of initial germination.

Harrington (10), working with flower seeds, noted that temperatures of 17.5°, 20°, and 30°C usually increased the rapidity of germination, while comparatively low temperatures were more favorable for the highest percentage of germination. The results obtained with wheat in these studies agree with this principle. On the average, at a temperature of 15°, there was more nearly complete germination than at higher temperatures. However, there was little difference between 10° and 15°, the latter temperature giving better germination than the former with Illinois No. 1 and Red Cross.

Detmer is cited by Schimper (18) as giving the cardinal points for the germination of wheat as 5°, 28.7°, and 42.5°C. The cardinal points refer to the minimum, optimum, and maximum temperatures for germination. Haberlandt, after Duggar (9), gives the cardinal points for the germination of wheat as 5°, 29°, and 42.5°C. Duggar states that these figures are merely suggestive and he expresses the opinion that various varietal and environmental factors affect the cardinal points of germination temperature. Percival (16) gives 22°C as the optimum temperature for wheat germination. Atterberg (2) gives 17°C, and Malsbury (13), in experiments with six varieties of Illinois wheat, reported a temperature of 15°C as most satisfactory. Coffman (6) states that all small grains, including wheat, can germinate at the temperature of melting ice, and that it appears advantageous to use lower temperatures for the germination of cereals than those commonly used in seed testing laboratories.

Table 1 shows that the germination of each variety, with the exception of Worlds Champion, reacted in the same general manner throughout the series of temperatures employed. Worlds Champion dropped sharply from a germination of 89% at 20°, to 20% at 30°. Many of the seeds showed no indication of germination at 30°. This decidedly marked decrease was due apparently to the genetic nature of this variety or to the environmental conditions under which it was grown. Unfortunately, it was impossible to secure samples of this variety from other stations, and this made it impossible to study the effect of different environmental conditions. A further study of this variety should prove of value, since not enough evidence is at hand to warrant final conclusions in regard to the interpretation of its behavior at a temperature of 30°.

The prevalence of mold attack increased markedly from the lower to the higher temperatures. As the seeds were placed under the less favorable conditions of high temperatures, they became more susceptible to mold attack. Also, the molds found more readily available food supplies at the higher temperatures and were more vigorous in their attack.

Wheats from other states gave much the same general reactions at low temperatures as did the homegrown wheats, as shown in Table 3. However, the entire group of wheats from other sections gave higher percentage germination at high temperatures than did the Illinois wheats. The most striking results were those secured with Marquis from North Dakota. This wheat germinated 92% at 30°, while Marquis from Illinois germinated only 55%. It appeared evident on the basis of the experimental work that the wheats of Illinois were not as resistant to the high temperature or to the molds growing under conditions favorable to optimum fungal attack as were the wheats from other states.

TABLE 3.—*Percentage germination of wheat varieties from various states and the percentage of moldy kernels failing to germinate at the constant temperatures indicated.*

Variety	Percentage germination at					Percentage moldy kernels at				
	10°	15°	20°	30°	All temperatures	10°	15°	20°	30°	All temperatures
Marquis, North Dakota	96	95	97	92	95	2	3	3	7	4
T. S. 3289–3 Texas ...	87	88	82	72	82	2	5	16	27	13
Rocky Mt., Virginia...	92	95	90	82	90	2	3	9	14	7
Turkey Red, Kansas....	89	89	89	72	85	1	3	8	25	9
Turkey Red, Indiana....	97	96	96	76	91	0	3	4	24	8

Schimper (18) states that the cardinal points for germination are higher for seeds of plants from warm countries than for those from cold regions. On the basis of results obtained in these studies it appeared that there was no noticeable change in the cardinal points of temperature for the germination of wheat from North Dakota as contrasted with those of wheat from Texas or Virginia. Percentage of germination was greater or practically the same for these wheats at low as well as at high temperatures. Except for the higher percentage of germination at high temperatures, the results coincided with the germination of Illinois wheat as shown in Table 1.

Samples of wheat appearing to be soft and relatively low in protein content gave the highest percentage of germination. Although the Turkey Red wheat from Kansas was a much higher grade sample than the same variety from Indiana, it failed to perform as well (Table 3) on the germinator. Mediterranean wheat from Texas gave a low germination record. This was expected as it was a rather inferior lot of seed. Mediterranean wheat from Virginia compared favorably with the Illinois seed and excelled the latter in germination at 30°. Marquis from North Dakota gave an exceedingly high percentage of germination at all temperatures employed, maintaining an average of 95% for all temperatures.

MOISTURE STUDIES

The moisture and temperature studies were made in parallel under controlled conditions in pots filled with a good grade of fine sand. The moisture-holding capacity of the sand was determined by the difference in weight between dry and saturated sand. The difference in weight gave the amount of water held by the sand with a saturation of 100%. From this difference, the various moisture percentages were readily calculated. The calculated grams of water were added as an equivalent number of cc. The sand and water were thoroughly mixed in a large mixing bowl and placed in pint, glazed earthenware jars to within one-half inch of the top. Ten kernels of wheat, equally spaced, were planted about three-fourths of an inch deep in the sand which had been previously compacted to provide uniform conditions for germination. A wax seal approximately 1 mm. in thickness was used to prevent loss of water by evaporation. The seal used was a mixture of vaseline and paraffin in the following proportions: For 10° and 15°C, 85 parts of vaseline to 15 parts of parowax, by weight; for 20° to 30°C, 80 parts of vaseline to 20 parts of parowax. Briggs and Shantz (3) recommend the use of 80% paraffin (M. P. 45°C) to 20% petrolatum. These proportions were found satisfactory at the higher temperatures, but a greater proportion of vaseline was necessary for the lower temperatures.

Jars, filled with sand containing 10, 30, 50, and 70% of water, were used for each variety. Each series was replicated four times giving a total of five jars which were placed in four controlled temperature cases at 10°, 15°, 20°, and 30°C. This made it possible to germinate the wheat under five different conditions of moisture at four different constant temperatures.

The general results of the moisture experiments indicate that wheat has capabilities of adaptation to widely differing moisture conditions, as shown in Table 4.

Heinrich (12), who used fine sand, reported best results from the use of 15% of water by weight in studies with garden seeds. Calculated on a similar basis, 50% moisture as used in this paper is equivalent to 11% by weight. This indicates that good results may be obtained with wheat germination from a lower amount of moisture than is best for garden seed.

The two spring wheat varieties, Illinois No. 1 and Marquis, gave best results with a moisture content of 50%. (Table 4.)

Of the soft red winter wheats, Red Cross gave best results with 50% moisture, while Mediterranean germinated slightly better with 30%. Furthermore, this variety gave nearly as good results with only 10% moisture and reacted approximately in the same manner with moisture contents of 50 and 70%, showing ability to germinate well under widely different moisture conditions (Table 4.)

The hard red winter varieties, Turkey Red and Worlds Champion, also gave best results with a low percentage of water and showed ability to germinate under widely varying moisture conditions.

The results with Worlds Champion show interesting variations from the usual behavior. For the three lower temperatures best results were obtained with 10% moisture, while there was but little change up to and including 70%. However, with 70% moisture, germination at 30°C was decidedly increased. This variety, as previously noted, germinated only 21% at 30°C in the temperature experiments (Table 1), and 26% with 10% moisture at 30° in the moisture experiments (Table 4). With an increase in moisture content there was a rise in germination percentage to a maximum of 76% when 70% moisture was used at 30°C. In the light of these results it might appear that the low germination of Worlds Champion at 30° in the temperature experiments was due to a lack of water. This does not entirely explain the differences obtained in total germination at 30° (Table 1), as imbibition is a physical process and all varieties were given the same conditions for imbibition to take place. Also, imbibition increases in direct ratio with increase in temperature, according to Brown and Worley (4); and as sufficient moisture was obtained for nearly perfect germination at low temperatures, it is apparent that it is not a question of obtaining sufficient water at a temperature of 30°. When the seed was surrounded by wet sand, there was more

TABLE 4.—*Percentage germination of Illinois wheat varieties under the conditions of moisture and temperature indicated.*

Variety	Temperature, degrees C	Percentage of germination with moistures of following percentages				
		10	30	50	70	Average
	10	62	80	80	68	73
	15	74	80	82	64	75
Illinois No. 1	20	74	76	78	64	73
	30	48	56	64	34	51
	Average	65	73	76	58	68
	10	84	86	88	82	85
	15	82	84	88	72	82
Marquis	20	86	76	80	64	77
	30	48	72	64	58	61
	Average	75	80	80	69	76
	10	78	90	98	88	89
	15	70	92	96	86	86
Red Cross	20	80	84	96	88	87
	30	34	82	82	80	70
	Average	66	87	93	86	82
	10	98	98	90	90	94
	15	96	98	100	96	98
Mediterranean	20	92	96	88	80	89
	30	76	82	76	72	77
	Average	91	94	89	85	89
	10	98	90	92	96	94
	15	100	98	98	96	98
Turkey Red	20	96	96	94	92	95
	30	46	80	80	80	73
	Average	85	91	91	91	90
	10	90	92	92	92	92
	15	98	96	94	96	96
Worlds Champion	20	98	90	90	92	93
	30	26	64	60	76	57
	Average	78	86	84	89	84

surface exposed to the water-bearing medium and this afforded greater opportunity for the imbibition process. It is possible that the greater amount of water promoted chemical changes which overcame inhibiting physiological conditions interfering with germination at 30°. Shull (19) found that absorption of water at different temperatures involved both physical and chemical changes.

In the light of the results obtained, it appears probable that the peculiar reaction of Worlds Champion wheat at a temperature of 30° is due to dormancy of the embryo caused by delayed after-ripening. The breaking of this type of dormancy through the use of low temperatures has been reported by numerous workers, among whom are Crocker (7), Munerati (14), Harrington and Hite (11), Pack (15), and Rose (17). Further studies are in progress to determine the true nature of the germination behavior of Worlds Champion wheat.

As the three varieties, Turkey Red, Mediterranean, and Red Cross gave good results with widely varying moisture contents and as the same varieties gave the highest percentage germination in the temperature experiments, it is suggested that a variety of wheat capable of good germination at high temperatures is likely to give good germination under widely varying conditions of soil moisture.

SUMMARY

1. As an average, a temperature of 15°C was more nearly optimum for complete germination of wheat than higher temperatures, although there was but little difference between 10° and 15°.

2. High temperatures of 20° and 30° gave more rapid germination, but lower temperatures of 10° and 15° gave more nearly complete germination.

3. In general, a temperature of 30° made the wheat kernel more susceptible to attack by molds. This temperature also gave more nearly optimum conditions for mold activity.

4. Worlds Champion wheat germinated very poorly at 30° under ordinary conditions. An increase in germination with increased amounts of water at 30° suggested that the water initiated chemical and physical changes making greater germination possible.

5. Wheats from Illinois, as well as those from other states, germinated best at temperatures of 10° and 15°.

6. Wheat showed wide adaptation to varying moisture conditions.

7. The spring and winter wheats tested exhibited the same general reactions to varying temperature and moisture conditions as winter wheats.

8. A moisture content of 50% of saturation gave good results with all wheat varieties studied.

9. The rate of initial germination of wheat at varying temperatures followed, in general, the principle of van't Hoff's law for chemical action.

10. The results of these studies confirmed the conclusion of Coffman (6), namely, that seed testing laboratories should employ lower temperatures for wheat germination than those now generally used.

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NATURAL CROSSING IN OATS AT MORGANTOWN, WEST VIRGINIA[1]

R. J. GARBER AND K. S. QUISENBERRY[2]

The extent of natural crossing among plants which are normally self-fertilized is of importance not only to the plant breeder but also to the grower of pedigreed seed. If natural crossing occurs it is always a possible source of contamination where two or more strains are grown in close proximity to one another. In genetic studies it is important to guard against extensive natural crossing, particularly so if one is working with a partially self-sterile strain.

Conflicting opinions have been expressed in regard to the extent of natural crossing in oats, some holding that it occurs relatively frequently, while others maintain that it is practically non-existant. Within recent years there have been reported the results of two carefully planned experiments to determine the extent of natural crossing in oats at two different places in the United States, namely, Akron, Colorado, and Saint Paul, Minnesota. The experiment at the former place was reported by Stanton and Coffman[3] and that at the latter place by Griffee and Hayes.[4] In both of these experiments it was demonstrated beyond doubt that natural crossing in oats does occur. No attempt will be made here to review the literature as a rather extensive survey has been made by Stanton and Coffman to which the reader is referred.

The investigation reported below had for its object the determination of natural crossing in oats at Morgantown, West Virginia.

MATERIAL AND METHOD

The material for this study was obtained from the oat-classification nursery grown at Morgantown, West Virginia, in 1921. Here each variety was grown in a short row containing approximately 20 plants with the rows 1 foot apart. In all cases the plants of a particular variety came from a single panicle selected the previous year. In the oat-classification nursery the varieties with light-colored seed, except Fulghum, used in the experiment to determine the extent of natural crossing were grown adjacent to other light-colored strains. Fulghum was grown between a variety with white seed and one with black seed. After the first year the seed for the natural crossing experiment was taken from the previous crop.

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[1] Approved for publication as Scientific Paper No. 32, by the Director of the West Virginia Agricultural Experiment Station, Morgantown, W. Va. Received for publication December 22, 1926.

[2] Professor in Charge and formerly Instructor, respectively, Department of Agronomy.

[3] STANTON, T. R., and COFFMAN, F. A. Natural crossing in oats at Akron, Colorado. Jour. Amer. Soc. Agron., 16:646–659. 1924.

[4] GRIFFEE, FRED, and HAYES, H. K. Natural crossing in oats. Jour. Amer. Soc. Agron., 17:545–549. 1925.

Inheritance studies have shown that black or brown seed color in oats is dominant, and therefore, to determine the extent of natural crossing, it was decided to grow Victor and Joanette, both dark-seeded varieties, adjacent to different light-seeded varieties and to test random samples of seed from the latter for the presence of natural crosses. An F_1 hybrid between a black-seeded plant and a light-seeded one may be detected easily on the basis of grain color among the progeny of the light-seeded parent.

The planting plan and the average date of heading of the varieties are shown in Table 1. Victor was grown adjacent to Fulghum, Gopher, Swedish Select, and Early Gothland, whereas Joanette was grown adjacent to Canadian, June, and Irish Victor. All of these varieties belong to *Avena sativa*, except Fulghum which belongs to the *A. byzantina* group.

The varieties were grown in rows 18 inches long and 1 foot apart. Twenty seeds were planted in each row. Each light-seeded sort, together with the adjacent dark-seeded form, was grown in four systematically distributed triple-row plats. In other words, the seeding as indicated in the planting plan shown in Table 1 was

TABLE 1.—*Planting plan and the average date of heading of the oat varieties in an experiment to determine the extent of natural crossing.*

Variety	Average date of heading		
	1922	1923	1924
Victor	June 20	June 25	July 8
Fulghum	June 18	June 24	July 5
Victor	June 20	June 23	July 6
Gopher	June 19	June 23	July 6
Victor	June 17	June 23	July 6
Swedish Select	June 18	June 26	July 8
Victor	June 19	June 23	July 6
Early Gothland	June 18	June 25	July 7
Victor	June 21	June 23	July 7
Joanette	June 19	June 25	July 4
Canadian	June 22	June 29	July 9
Joanette	June 19	June 24	July 5
June	June 23	June 30	July 10
Joanette	June 19	June 27	July 5
Irish Victor	June 22	June 30	July 8
Joanette	June 18	June 25	July 5

replicated three times in each of the three years this phase of the experiment was under way.

In order to obtain natural crossing it is necessary that the blooming periods in the two varieties approximately coincide. Gopher and Fulghum bloom considerably earlier than Victor, but by planting them about two weeks later than Victor the three sorts bloom at approximately the same time. The average date of heading of each variety was determined in order to obtain the relative time of blooming. A particular row was marked headed when from one-half to two-thirds of the panicles had emerged from the boot.

EXPERIMENTAL DATA

The average dates of heading of each variety of oats used in this experiment are shown in the second, third, and fourth columns of Table 1. In general, the sorts grown in adjacent rows headed at about the same time. The greatest and most consistent difference occurred between the varieties Joanette and June, the differences between the average dates being four days each in 1922 and in 1923, and five days in 1924. The difference in the time of blooming of these two varieties was not great enough, however, to prevent natural crossing as in 1922 a natural cross occurred between them.

The relative number of F_1 plants owing to natural hybridization is shown in Table 2. No plant was considered an F_1 until its progeny had proved it to be one. It will be observed that only one natural cross was found among 7,742 *A. sativa* plants and that one occurred between June and Joanette in 1922. There were examined during three years 1,319 Gopher, 1,262 Swedish Select, 1,341 Early Gothland, 1,232 Canadian, 1,290 June, and 1,298 Irish Victor plants. In contrast to the low frequency of natural crossing between varieties of *A. sativa*, there was considerable crossing between Fulghum ♀ (*A. byzantina*) and Victor ♂ (*A. sativa*). Out of a total of 1,708 plants of Fulghum examined 7, or 0.41%, proved to be hybrids. In addition to the Fulghum plants in the natural crossing experiment there were grown in 1925, 331 plants from Fulghum seed produced adjacent to a black-seeded *sativa* form in the oat-classification nursery in 1921. Among these plants there was one natural hybrid. Although there were fewer plants examined in 1923, relatively more F_1 plants (0.91%) were found in that year than in the other two years. This fact indicated that more natural hybridization took place in 1922 than in 1923 or 1924. It will be recalled that the F_1 plant found in the variety June was also produced by natural cross-pollination in 1922.

TABLE 2.—*Natural crossing in oats at Morgantown, W. Va.*

Variety	Year[a]	Total number of plants	Number of natural crosses	Percentage of crossing
Fulghum (*A. byzantina*)	1923	330	3	0.91
	1924	509	2	0.39
	1925	538	1	0.18
	1925[b]	331	1	0.30
		1,708	7	0.41
Gopher (*A. sativa*)	1923	277	0	0
	1924	500	0	0
	1925	542	0	0
		1,319	0	0
Swedish Select (*A. sativa*)	1923	309	0	0
	1924	475	0	0
	1925	478	0	0
		1,262	0	0
Early Gothland (*A. sativa*)	1923	306	0	0
	1924	488	0	0
	1925	547	0	0
		1,341	0	0
Canadian (*A. sativa*)	1923	245	0	0
	1924	475	0	0
	1925	512	0	0
		1,232	0	0
June (*A. sativa*)	1923	287	1	0.35
	1924	494	0	0
	1925	509	0	0
		1,290	1	0.08
Irish Victor (*A. sativa*)	1923	272	0	0
	1924	514	0	0
	1925	512	0	0
		1,298	0	0
Grand total (*A. sativa*)		7,742	1	0.013

[a] Natural crosses actually occurred one year previous to the dates indicated in this column. The dates recorded here are the years in which the F_1 plants were observed.

[b] Natural cross occurred in oat-classification nursery in 1921.

In order to test the purity of the Fulghum stock, 35 panicles were selected from the same row in the oat-classification nursery which supplied the original seed of this variety for the natural crossing experiment. The seed of each of these 35 panicles was sown in a separate plat isolated in a field of maize. The plats were placed approximately 20 feet apart so as to prevent cross-pollination between strains. There were grown a total of 331 plants and one proved to be a hybrid (black seed color) as was pointed out above. The fact that the particular row in the oat-classification nursery which supplied the 35 panicles was adjacent to a black-seeded form probably accounts for the black-seeded F_1 plant. However, to determine whether this black-seeded plant was most likely produced by mutation or by natural crossing, the following test was made. A random sample of about 500 seeds was taken from each of 19 of the 35 strains of Fulghum. The strain in which the black-seeded plant occurred, as well as all strains which were grown nearby, was not used in this test. The 19 seed samples were sown in separate plats in such a way as to permit individual plant study. In all there were grown and examined 8,178 plants and each showed a grain color typical of the Fulghum variety. This is at least negative evidence in favor of the conclusion that the above-mentioned black-seeded plant, as well as the F_1 black-seeded plants obtained in the Fulghum variety in the natural crossing experiment, were produced by natural hybridization and not by mutation.

NATURAL CROSSING AND THE WEATHER

The experiments to determine the extent of natural crossing at Akron, Colorado, and at St. Paul, Minnesota, were conducted under climatic conditions which, perhaps, are more favorable to natural crossing than those which occur at Morgantown. The nature of the weather which prevailed during the blooming period of the oats in this experiment is shown in Table 3. The time which elapsed between the fourth day the first plat was marked headed and the third day after the last plat was so marked was considered the blooming period.

During the blooming period rain fell on one day only in 1922 and on seven days each in 1923 and in 1924. The relative amount of natural crossing obtained between Fulghum and Victor was greatest in 1922. Moreover, the only natural cross obtained between varieties

TABLE 3.—*The daily mean temperature and the rainfall during the blooming period of certain oat varieties at Morgantown, W. Va.*

June, 1922

	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Rainfall, inches....	0	0	0	0	0.70	0	0	0	0	0	0	0	0	0	0
Temperature, degrees...	61	68	70	73	77	68	71	74	72	67	62	70	75	65	75

June, 1923 / July

	20	21	22	23	24	25	26	27	28	29	30	July 1	2
Rainfall, inches......	0	0	0	0	0.19	1.47	0.27	T[a]	1.30	T[a]	0	0	T[a]
Temperature, degrees.	79	79	82	80	76	74	78	68	67	62	57	63	68

July, 1924

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Rainfall, inches..	T[a]	0	0	0.14	0	0.74	0.34	0.12	0	0.36	0	0	0.76	0
Temperature, degrees.......	63	63	63	69	—	72	73	76	74	75	70	74	74	68

[a] Trace.

of *A. sativa* occurred in 1922. This evidence, although meagre, indicates that natural crossing in oats is favored more by dry rather than by rainy weather.

The mean daily temperatures fluctuated considerably. Relatively high temperatures followed by rather low temperatures prevailed during the blooming period in 1923, whereas just the reverse condition obtained in 1924. Wide variations in temperature were also observed in 1922.

DISCUSSION AND CONCLUSION

The data of Griffee and Hayes show that considerably more natural crossing was obtained in Kanota, a strain of Fulghum, than in the varieties of *A. sativa.* The data presented here likewise show considerable more natural crossing in Fulghum than in the *sativa* varieties. The frequency of natural crossing between Fulghum and admixtures[5] contained in it may be one of the reasons why this variety seems so difficult to purify. The apparent instability of other forms of *A. byzantina* has been attributed to mutations. It is of course possible that mutations and natural crossing both bring about contamination of a variety. Relatively high self-sterility may indirectly bring about more extensive cross-pollination. Wakabayashi[6] showed that more self-sterility existed in Red Rustproof (*A. byzantina*) than in Black Tartarian (*A. sativa orientalis*).

In experiments similar to the one discussed in this paper it is customary to double the percentage of natural crossing actually obtained and consider the resultant percentage as the amount of natural crossing which leads to varietal contamination Such a procedure is questionable in the case of crosses between *A. byzantina* and *A. sativa.* There is evidence in the data presented by Griffee and Hayes, as well as in the data presented above, that natural crossing takes place more frequently between *A. byzantina* ♀ and *A. sativa* ♂ than with the reciprocal relationship. The Black Victor variety cross-pollinated Fulghum more frequently than it did any of the varieties of *A. sativa.*

The extent of natural crossing between varieties of *A. sativa* at Morgantown is relatively low. Among a total of 7,742 plants examined during three years only one natural cross was found. On the other hand, there was as much as 0.91% natural crossing between Fulghum ♀ and Victor ♂, the average being 0.41% based on a total of 1,708 plants.

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[5] Admixtures as used here may be defined as individuals which do not have the genotype of true Fulghum.

[6] WAKABAYASHI, S. A study of hybrid oats, *Avena sterilis* x *Avena orientalis.* Jour. Amer. Soc. Agron., 13:259–266. 1921.

The climatological data indicate that the nature of the weather may influence natural crossing in oats. In 1922, rain fell on one day only of the blooming period, whereas in 1923 and 1924 rain fell on about one-half of the days during the blooming periods. Four of the six natural crosses found during these three years occurred in 1922.

Evidence is presented which indicates that the black-seeded forms found in Fulghum in this experiment are due to natural crossing and not to mutation.

NOTES

RAPID DETERMINATION OF THE MOISTURE CONTENT OF SOILS

One of the greatest needs in soils investigations, both in the laboratory and under field conditions, is a simple and very rapid method for determining the moisture content of soils. The same need is undoubtedly felt in many other branches of science and industry, for the methods we have at present for determining moisture content of materials are laborious, slow, and time-consuming.

In having developed and used in this laboratory the hydrometer method for estimating the mechanical composition of soils and also for determining the colloidal content of soils in only a few minutes, the idea occurred that the hydrometer method might be used also in determining the moisture content of soils. This could be done, it was thought, by mixing a definite volume of pure alcohol of known specific gravity and a definite amount of moist soil and determining again the specific gravity of the liquid. The difference in specific gravity between the pure alcohol and the mixed liquid ought to give the amount of water in the soil since the alcohol extracted the moisture from the soils which went to dilute its strength.

This idea was subjected to an investigation and it proved to be perfectly correct and successful. The experiments showed that the alcohol can extract the moisture from the soil from any moisture content down to considerably below the air-dry condition, and it indicates the amount so extracted correctly on its specific gravity. When the soil mass is in such a structure so the alcohol can penetrate it easily, the extraction of the moisture is accomplished almost instantaneously. The soil particles not being deflocculated by the alcohol, they settle to the bottom of the vessel very readily. On the other hand, for more rapidity in operation, the soil can be shaken vigorously, immediately filtered, and the specific gravity of the filtrate taken. The results showed that whether the alcohol mixture was allowed to clear up by standing or filtered through a filter paper, the specific gravity was the same.

By means of this method the moisture content of a soil can be determined in only a few minutes. At this laboratory the moisture content of many soils has been determined in less than five minutes. The only soils which take more time are those which are puddled and the alcohol cannot penetrate them. Vigorous shaking or stirring with a rod, however, hastens their breaking up.

This method seems to be absolute and not arbitrary. It seems that it is almost as absolute as the oven-dry method. With a very sensitive and accurate hydrometer, which is being made, the method can be very accurate. As a matter of fact the method has a most surprisingly high degree of accuracy as will be seen from the following representative results as obtained from a comparison of this method with the oven method.

Soils	Moisture by alcohol method	Moisture by oven method
	%	%
Brookston clay loam A_1	18.31	18.98
Brookston clay loam A_2	13.96	14.71
Brookston clay loam B	14.52	15.43
Fox sandy loam B_1	12.11	12.28

The method ought to find a very wide application, not only in soils work and possibly in plant tissues, but also in many other sciences and industries. It is somewhat strange that it has not been used long before this, because we have known its principle for so long.

A more detailed report is being prepared.—GEORGE BOUYOUCOS, *Research Assistant in Soils, Michigan State College, East Lansing, Mich.* (Reprinted, with additions by the author, from Science, 64: 651–652. 1926.)

METHODS OF APPLYING LIME

It is generally recognized that one of the causes of clover and alfalfa failures on numerous soil types in the humid regions of the United States is the deficiency of lime, especially in the A and B horizons. Owing to the expense and labor required to add lime to the entire tilled land, it is very difficult for the majority of farmers to carry on a satisfactory crop sequence, except on a relatively small percentage of their land under cultivation. It is lamentably true in fact that only a small percentage of the farmers practice proper crop rotation. This condition will have to be rectified soon—otherwise there will be a great deficiency in the nitrogen content of these soils.

Several field trials are in progress at the Michigan Experiment Station of the possibility of the use of small amounts of lime in the row at the time of seeding of legumes as is done in the fertilization of the small grains. The results of one set of these tests are presented herewith. This was inaugurated in the spring of 1923. In this test, in which alfalfa is the indicator employed, hydrated lime and finely ground limestone were drilled with the seed and also broadcasted in the usual manner. The Superior grain drill with grass seeder attachment was used in drilling the seed and applying the lime in the row. The seed and lime were delivered through the same tubes, thus placing them in contact with each other in the soil.

It was thought that the local application of the lime near the seed might meet the lime requirement of a small portion of the soil and perhaps furnish the plants with sufficient lime. Perhaps in this way a small application would suffice, especially for legumes that occupy the land a short time as in the case of the clovers. The results thus far obtained appear to be promising where the soil types are not too acid.

A summary of the results obtained on Fox sandy loam soil is given below. The total weights of dry hay removed from two cuttings in 1924, two in 1925, and one in 1926 are recorded.

Results obtained in five alfalfa cuttings from applying lime in different amounts and by different methods.

Form of lime	Amount applied, pounds	Method of application	Dry weight of hay per acre, pounds
Hydrate	350	row	4,904
Hydrate	750	row	9,213
Finely ground limestone	350	row	5,747
Finely ground limestone	750	row	9,044
None			4,788
Hydrate	620	broadcast	5,974
Hydrate	1,500	broadcast	7,396
Hydrate	3,000	broadcast	11,881
Finely ground limestone	620	broadcast	6,724
Finely ground limestone	2,000	broadcast	8,617
Finely ground limestone	4,000	broadcast	9,913

These results appear to indicate that 750 pounds applied in the row is as effective as much larger applications sown broadcast. Further trials are in progress.—M. M. McCool, *Professor of Soils, Michigan State College, East Lansing, Mich.*

AGRONOMIC AFFAIRS

COMMITTEE TO STUDY FERTILIZER DISTRIBUTING MACHINERY

The President of the Society has changed the personnel of this Committee for the year to be as follows: Emil Truog, Chairman, J. R. Fain, and F. E. Bear.

NEWS ITEMS

The present engagement of Howard B. Sprage was incorrectly stated in the "News Items" in the December issue of the JOURNAL. He has been Assistant Professor of Agronomy in the University of Minnesota and Assistant Agronomist of the Minnesota Agricultural Experiment Station at St. Paul since July 1, 1926.

After a year's study at Rothamsted in England as a fellow of the International Education Board, Charles E. Skinner resigned his position at the New Jersey Agricultural Experiment Station on October 1, 1926, to become a member of the teaching staff of the bacteriology department at the University of Minnesota.

W. R. Singleton has been appointed Assistant Geneticist at the Connecticut Agricultural Experiment Station at New Haven.

Herbert C. Brewer has recently been appointed Director of Educational work for the Chilean Nitrate of Soda Educational Bureau, with headquarters at 57 William St., New York City. The Bureau maintains branch offices in eleven southern states and has recently appointed state managers to be located at each of these offices to cooperate with state experiment station officials, county agents, and farmers in educational work. The following have been appointed as state managers: Homer H. B. Meek, Raleigh, N. Car.; H. E. Savely, Columbia, S. Car.; T. H. Bonner, Hurt Bldg., Atlanta, Ga.; Frank E. Boyd, Montgomery, Ala.; C. M. Tingle, Jackson, Miss.; R. S. Cuncliffe, Hibernia Bank Bldg., New Orleans, La.; Wm. H. Jones, Memphis, Tenn.; George L. Foster, Athletic Bldg., Dallas, Texas; W. L. MacArthur, Little Rock, Ark.; J. F. Bazemore, Orlando, Fla.; and H. L. Perry, Mayaguez, Porto Rico.

P. C. Mangelsdorf resigned as Assistant Geneticist of the Connecticut Agricultural Experiment Station on January 1 to become Agronomist in charge of corn and small grain investigations at the Texas Station.

Stanley F. Morse, consulting agricultural engineer, sailed for South America on January 15, to investigate soil and sugar cane production problems in British Guiana for an English sugar company. He will visit also the Imperial College of Tropical Agriculture in Trinidad.

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SYMPOSIUM ON "PLANT BREEDING"

Leader: H. K. Hayes, Professor of Plant Breeding and Plant Breeder in Charge of the Section of Plant Breeding, Division of Farm Management, Agronomy, and Plant Genetics, Department of Agriculture, University of Minnesota.

1. "The Relation of Triploid Factors and Chromosome Groups in Wheat and Oats." E. F. Gaines, Washington Agricultural Experiment Station.

2. "Breeding Wheat for Resistance to Physiologic Forms of Stem Rust." O. S. Aamodt, Bureau of Plant Industry, U. S. Department of Agriculture.

3. Discussion—"Breeding Plants for Disease Resistance." C. E. Leighty, Bureau of Plant Industry, U. S. Department of Agriculture.

4. "Breeding Improved Varieties of Forage Crops." L. E. Kirk, Department of Field Husbandry, University of Saskatchewan.

5. Discussion—"Progress and Possibilities in Forage Crop Improvement." P. C. Mangelsdorf, Connecticut Agricultural Experiment Station.

6. "The Accurate Determination of Dry Matter in Forage Crops." G. P. McRostie and R. I. Hamilton, Dominion Department of Agriculture of Canada.

1. THE RELATION OF TRIPLOID FACTORS AND CHROMOSOME GROUPS IN WHEAT AND OATS[1]

E. F. Gaines[2]

The literature of the past 20 years on wheat and oat hybrids shows many cases where multiple factors are involved in producing a given character. Without attempting to make a complete list, a few common references may be cited. Nilsson-Ehle (8)[3] of Sweden, in 1909, found red grain color in wheat to be caused by three independent factors. Third generation families were obtained which gave three different types of ratios of red and white grain as follows: 3:1, 15:1, and 63:1. This showed beyond doubt that three different chromosomes each carried a gene for red color. Gaines (3), in 1917, found a parallel case in which only 13 white-seeded F_2 plants appeared in a total population of 539. The 280 F_3 families which were analyzed the next year gave the following results:

168 families gave pure red
30 families gave 63 (red): 1 (white)
48 families gave 15 (red): 1 (white)
28 families gave 3 (red): 1 (white)
6 families gave pure white.

Waldron (17), in 1924, reported the occurrence of dwarf plants in the progeny of crosses between normal wheats in ratios that necessitated some kind of a three-factor hypothesis, but was unable to devise one to account for all the conditions observed. The dwarf factors reacted as recessives in one case, as dominants in another, and as two dominants and one recessive in a third.

According to Gaines (4, 5), resistance to bunt in wheat resulted from the cumulative effect of three factors in the crosses made at the Washington Agricultural Experiment Station between the resistant varieties Turkey, Florence, and Alaska, and the susceptible varieties Jenkin, Hybrid 128, and Jones Fife.

Powers (12) found the winter habit of growth of Hybrid 128 differing from Velvet Node by three factors which were cumulative in effect. Any one factor acting alone would produce a type somewhat later than Velvet Node and two would make the segregate head and mature grain still later, while all three factors acting together would prevent the plants from heading when spring sown. This is a difficult character to study because it is associated with the amount of daylight received. The relative length of day and night changes as the season progresses. Spring habit reacts as a dominant from early sowing and as a recessive from very late sowings. Intermediate dates of sowing give intermediate reactions. In this particular cross (Hybrid 128 x Velvet Node) when planted April 4, the factors A and B were partially dominant for spring habit while C was recessive in the absence of A and B.

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[1] Paper read by title as a part of the symposium on "Plant Breeding" at the meeting of the Society held in Washington, D. C., November 19, 1926. Published with the approval of the Director of the Washington Agricultural Experiment Station as Scientific Paper No. 137, College of Agriculture and Experiment Station.

[2] Cerealist, Washington Agricultural Experiment Station, Pullman, Wash.

[3] Reference by number is to "Literature Cited," p. 205.

Caporn (2), working with earliness in oats, found a three-factor difference in time of ripening in a cross between Mesdag and Hopetown. The F_1 was intermediate. The F_2's were all harvested together and 106 plants tested in the F_3 generation. Two were homozygous for early maturity equivalent to Mesdag. The lateness of Hopetown was not recovered.

Nilsson-Ehle (8) found the color of the lemma to be caused by three factors. This interpretation was also verified by Surface (16) in a cross with Kherson and wild oats.

Wakabayashi (18) found the immunity from covered smut of Red Rustproof to be due to three factors in a cross with Black Tartarian. Later, Gaines (6) found the three-factor hypothesis to hold in crosses of Red Rustproof with Abundance and two varieties of hulless oats. Data on F_3 families of Markton x Large Hulless and Markton x Banner, grown at Pullman, Washington, in 1926, and as yet not completely analyzed, show the immunity of Markton to be dominant but controlled by multiple factors—probably three.

These illustrations show that a number of taxonomic and physiologic characters are caused by three independent factors. A larger list could be compiled showing a dihybrid reaction to such characteristics as grain color, awning, disease resistance, and growth habit. Many more respond to a unit factor interpretation (3, 8, 10, 19).

The frequency of the occurrence of two or three independent factors affecting a single character might be due to certain chromosomes being more closely related than others. If three chromosomes had a number of genes in common, the 63:1 ratio, or some modification of it, would show up as often as the particular character met its opposite carrying the three normal allelomorphs. In the third generation seven types would appear. Four would be homozygous and three would be heterozygous. The three heterozygous forms would give ratios of 63:1, 15:1, and 3:1. The red grain color illustrates this. Homozygous types with dark, intermediate, and light red grain were isolated. The plants with white grain bred true and the three ratios 63 red: 1 white, 15 red: 1 white, and 3 red: 1 white were obtained.

Sakamura (13) made the first accurate study of chromosome numbers in the genus *Triticum* in 1918. Kihara (9) followed in the next year with a paper on chromosome number in oats. The basic number is found to be seven in both crops. Einkorn wheat and a wild oat, *A. strigosa*, each have seven pairs of chromosomes in their root tips. Emmer, durum, polish, and poulard wheat and *A. barbata* oats have 14, while spelt and the bread wheats, as well as all cultivated oats, have 21.

Aase and Powers (1) last year counted the chromosomes in the meiotic stages of the microspore mother cells of 18 species and varieties of wheat and oats, but found only the 7, 14, and 21 groups reported before. Many crosses between these groups have been made with wheat. When the 14 and 21 groups are crossed, the 35 chromosomes are arranged in 14 paired and 7 single chromosomes in the first reduction division, according to Sax (14). When the 7 and 14 groups are crossed, there are 7 bivalents and 7 univalents at the reduction division. The 7 and 21 combination has not been studied cytologically to the writer's knowledge, but theoretically there should be 7 paired and 14 singles at the reduction division. When rye with 7 is crossed with wheat with 21 chromosomes, there is no pairing except an occasional end to end fusion, showing slight compatibility (work in progress at Washington State College). When *Aegilops cylindrica* with 14 chromosomes is crossed with wheat with 21, there are 7 paired and 21 singles in the meiotic stages of the microspore mother cells, according to the Saxs (15) and Gaines and Aase(7). If, however, a wheat (Alaska) with 14 chromosomes is crossed with *Aegilops*, no pairing occurs as in the wheat-rye crosses. This suggests that the bread wheats arose by a doubling of the chromosomes in a cross between the 14 chromosome group of wheats and *Aegilops*, 7 of whose 14 chromosomes were lost in the shuffle. The taxonomic characters of the two forms, according to Percival (10), bear out this assumption. *Aegilops cylindrica* contributes the thin-walled hollow stem, beardlessness or short awns, rounded outer glumes, the long hairs on the ridges of the young leaf blades, and the winter habit of growth. The durum or emmer group has the longer straw, tough rachis, keeled glumes, and long awns.

Such characters as red and white grain color, resistance and susceptibility to stinking smut, and spring and winter habit of growth are probably common to both races. Hence, the three multiple factors for such characters in certain crosses. The three chromosomes that carry factors apparently stay within their own group of seven, as there is no evidence of linkage, or of the groups from one parent mating with each other in synapsis as might have been anticipated in the haploid wheat plant, according to Gaines and Aase (7) and as suggested by Percival (11).

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2. BREEDING WHEAT FOR RESISTANCE TO PHYSIOLOGIC FORMS OF STEM RUST[1]

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Resistance to plant pathogenes deserves serious consideration in a crop-improvement program. The existence of physiologic forms in pathogenes which cause some of the most destructive plant diseases has added considerably to the complexity of the problem. The inheritance of disease resistance may be complicated not only because of the presence of many and varied forms of the pathogene, but also because disease resistance is the result of the interaction of two elements, i. e., the host plant and the parasite. The mode of inheritance of reaction to the various physiologic forms of stem rust aids materially in deciding how extensively any particular cross must be studied. Furthermore, from the practical standpoint, one must have a variety which is resistant to all the forms present in the region where the variety is to be grown.

Varietal testing and breeding of spring wheat for resistance to stem rust were started at the University of Minnesota about 1907 by E. M. Freeman and E. C. Johnson as a cooperative project between the Minnesota Agricultural Experiment Station and the United States Department of Agriculture. The earlier work consisted primarily of varietal testing, and, in a much more comprehensive form, is still being carried on cooperatively by the United States Department of Agriculture and various state agricultural experiment stations. At the University of Minnesota the problem is being attacked cooperatively by the sections of Plant Breeding and Plant Pathology and the Office of Cereal Crops and Diseases of the United States Department of Agriculture.

In crop improvement, the line of development usually is placed in three categories: First, the testing of domestic and foreign varieties; second, selection; and third, hybridization. The testing of established varieties naturally is the first step in the search for strains to meet particular requirements. This method usually is supplemented by the introduction of foreign varieties. A large number of varieties and strains of wheat have been introduced at various times in attempts to discover some that would prove resistant to rust and drought. Research in this field was greatly stimulated by the foreign collections made by the United States Department of Agriculture and introduced into this country by M. A. Carleton (5)[3] in 1900. These varieties were principally hard red winter and durum wheats and did not supply the needs of the hard red spring-wheat millers.

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[1] Paper read as a part of the symposium on "Plant Breeding" at the meeting of the Society held in Washington, D. C., November 19, 1926. The data presented in this paper were obtained in cooperative investigations between the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, and the Department of Agriculture of the University of Minnesota.

[2] Associate Pathologist, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, in cooperation with the Agricultural Experiment Station, University of Minnesota. The writer is indebted to Doctors H. K. Hayes and E. C. Stakman for suggestions in the preparation of this paper and for the use of unpublished data on phases of the problem which are a part of the general cooperative project.

Selection is a desirable first step in the improvement of a crop. If the material from which the selections are made happens to have variables of the desired type they may be discovered. The method of origin of such individuals usually is unknown. Kanred winter wheat is one of the more recent examples of a selection possessing considerable merit.

If the desired type is not found among the established varieties or selections, then the next avenue of pursuit is hybridization. Before making crosses, it is necessary to obtain parents which exhibit certain desirable characters. In order to do this, careful studies of all available strains and varieties must be made and particular attention paid to the characters of most importance. Some of the durum wheats proved resistant to rust but were undesirable for making bread. Marquis and other varieties of *Triticum vulgare* were very desirable bread wheats, but very susceptible to stem rust. Difficulties were encountered in the transfer of rust resistance from the durum wheats and emmers to the common wheats. The linkages between species characters and resistance to rust were such that progress in the production of desired recombinations was slow. By the use of large numbers in F_2 and F_3, resistant common wheats have been obtained from crosses of common susceptible wheats with resistant durum and emmers (7, 10, 11). Several common wheats are now known to be resistant under field conditions to some or all of the known physiologic forms found in this country.

Marquillo [Minnesota No. 2202, and C. I. 6887[4] (7,10)] is a promising selection obtained from a cross between Iumillo, a rust-resistant durum, and Marquis, a common wheat. This variety is known to have the chromosome number of common wheats. It is rust resistant and a high yielder, and baking tests show it nearly equal to Marquis in baking strength.

Hope (C. I. 8178) and other selections from the same cross are hybrids produced by McFadden (11) by crossing Vernal emmer and

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[3] Reference by number is to "Literature Cited," p. 218.

[4] C. I. refers to Cereal Investigations number.

Marquis wheat. They are common wheats and from counts made by Dr. Fred Griffee are known to contain the chromosome number of common wheats. In the field tests, they are the most rust resistant common wheats known and appear very promising, especially as material for crosses.

Another difficulty encountered in the earlier work was the failure of some of the new productions and varieties to maintain their resistance in the field every year, and in all localities. Varieties, resistant in one locality, were sometimes susceptible in another, and vice versa. A correct explanation of the cause of this variation in reaction to rust was not forthcoming until the discovery of the existence of physiologic forms of stem rust by Stakman and Piemeisel (15) in 1917. It soon became evident that a variety of wheat did not lose its resistance to any particular rust form, but, when grown in a different locality or in a later year, it was attacked by rust forms to which it had not previously been exposed. The first clue to this discovery was that supplied by Marquis wheat when it showed resistance in the greenhouse to certain cultures of stem rust collected on the Pacific Coast. Later it was discovered that this variety, which is usually susceptible in the hard red spring-wheat region, sometimes exhibited marked resistance when grown on the Pacific Coast or in the South. The separation of *Puccinia graminis tritici* (Pers.) Eriks. & Henn. into distinct physiologic forms was demonstrated when it was shown that Marquis was susceptible to some of the cultures and resistant to others.

An interesting case was one which came to light in the development of Mindum, a variety of durum wheat. This variety was produced by selection at University Farm, St. Paul, and was outstanding in several respects, included among which was its resistance to stem rust. When Mindum was grown at the Crookston Branch Station, however, it proved very susceptible in some years when certain physiologic forms to which it was susceptible were present in the field. Evidently these forms usually were not prevalent in the vicinity of St. Paul. Mindum has since then been shown to be very susceptible when grown at University Farm under an artificially induced epidemic of black stem rust. In the production of the artificial epidemic, forms of rust were used which had been collected at Crookston.

Kanred, a variety of hard red winter wheat, is immune from 11 of the physiologic forms of stem rust (18). Kanred often is spoken of as a resistant variety. It has been observed, however, to be severely injured by stem rust in the field at certain times when particular rust forms were present to which it is normally susceptible.

From the illustrations just presented it is evident that when one speaks of a variety of wheat being resistant or susceptible it can only be in a general sense. Such a wheat as Marquis, which one might ordinarily think of as a susceptible variety, is really resistant to 12 of the first 37 forms identified (18).

Questions of paramount importance to this problem naturally arise. How many physiologic forms of *Puccinia graminis tritici* are there? What is the prevalence and distribution of the forms? Dr. Stakman and his co-workers soon demonstrated the existence of numerous forms. A survey of their prevalence and distribution was inaugurated and is still in progress. The seeming loss of resistance of certain wheat varieties and hybrids to stem rust is now explained by the change in distribution of rust forms from year to year. In 1922, Stakman and Levine (18) reported the existence of 37 physiologic forms of stem rust. Each form is a definite genetic entity. To collect and maintain cultures of all of these forms for breeding studies is not an especially easy task. The knowledge of the existence of numerous physiologic forms was of considerable value in formulating plans for the production of a hard red spring wheat resistant to black stem rust.

The natural mode of attack on a problem of such complexity is to ascertain the validity of some of the theoretical considerations regarding the genetic relationship between the host and the parasite. Can physiologic forms of stem rust on wheat change rapidly enough to interfere with breeding for rust resistance? After a study of the plasticity of particular forms in the urediniospore stage, Stakman, Piemeisel, and Levine (17), Stakman, Parker, and Piemeisel (16), and Peltier (13) concluded that the various forms were stable and retained their identity when cultured on different hosts. The reaction between host and parasite is a genetic character and is not subject to extreme variation by season, soil types, location, or other environing conditions (19).

There already are many more known forms of stem rust than there are chromosome pairs in our bread wheats. If the resistance to one physiologic form was alternative in inheritance to a second form, or if there was a series of multiple allelomorphic factors for the different forms, it would be impossible to combine resistance to all forms in one variety. Also, if the factor for resistance to one physiologic form should be closely linked with a factor for susceptibility to a second form, it would be difficult to obtain a variety resistant to both forms.

In a genetic study of the mode of reaction to particular physiologic forms, it is quite necessary that the work be carried on under controlled conditions. If one of the parents in a cross was resistant to a physiologic form of rust, the transfer of this character to its progeny could be accurately determined only by testing the progeny with a pure culture of the form studied. In the field, all plants might appear equally susceptible, owing to the presence of other forms to which one or both parents were susceptible. In such a general field epidemic it would be difficult, or practically impossible, to differentiate one plant from another.

In 1911, Barrus (2) reported the existence of physiologic strains of the organism causing bean anthracnose. Burkholder (3), in 1918, and McRostie (12), in 1919, demonstrated that the resistance to these strains (alpha and beta) could be combined in a single desirable commercial variety. A few years later (4) a third form (gamma) appeared which was able to attack the variety which was resistant to alpha and beta. By further crossing, a new recombination was obtained which brought together the resistance to all three physiologic forms.

In breeding for stem rust resistance it was decided, therefore, to learn the possibility of obtaining in a single variety the resistance of two varieties of wheat which react reciprocally to two physiologic forms of rust. Puttick (14) probably was the first to demonstrate such a recombination in a cross between a common and a durum wheat. Harrington and Aamodt (6), working with durum wheats, and Hayes and Aamodt (9), with common wheats, later demonstrated that such a recombination was possible. All of these studies were made in the greenhouse, under controlled conditions, and with pure physiologic forms of stem rust. A tabular summary of the results obtained from these crosses is given in Table 1.

TABLE 1.—*Recombinations of the resistance of two wheat varieties with reciprocal reactions to two physiologic forms of Puccinia graminis tritici.*

Type	Parents	Physiologic forms	Number of hybrid plants or lines		Remarks
			Total	Resistance to both forms	
Interspecific	Marquis x Mindum	1 and 19	338	35	F_2 plants
Intraspecific	Pentad x Mindum	1 and 34	110	6	F_3 lines
	Kota x Marquis	19 and 27	372	3	F_3 lines

The hybrids are the progeny of an interspecific cross between a durum and a common wheat and intraspecific crosses in durum and common wheats. A number of individuals were obtained in each of the three crosses which have the resistance reaction of both parents to these particular forms. The results reported furnish genetic evidence in support of the belief that resistance to different physiologic forms which are inherent in two different varieties of wheat either are independent or only partially linked.

Further studies of the reaction of species crosses to particular physiologic forms of stem rust have demonstrated the possibility of combining the resistance of one parent with the desirable morphological characters of the other parent. Khapli emmer is resistant to all forms of stem rust found in this country (18). From 75 or 90% of the kernels of Khapli remain enclosed in the glumes after threshing. Mindum is a high-quality amber durum, but it is susceptible to certain forms of rust. Pure cultures of five physiologic forms of rust to which Khapli is resistant and Mindum susceptible were used in a study of the reaction of the progeny from a cross between these two varieties. There was only sufficient seed from each individual plant to test the seedlings for rust reaction to but two forms of rust. Consequently, the F_3 progeny were placed in four random groups and the seedlings of each group were inoculated with urediniospores of two physiologic forms (Table 2). Several thousand F_2 and F_3 plants were grown in the field under an artificial epidemic of black stem rust. In the F_2 all plants which were vigorous, resistant to rust, and high in free-threshing percentage, as well as a few plants representing various other grades of threshing, were selected for growing in the F_3. The results obtained in the greenhouse studies are summarized in Table 2.

TABLE 2.—*Recombination in wheat-species crosses of resistance to stem rust with a high free-threshing percentage and common-wheat type.*

		Number of hybrid lines			
Cross and generation	Physiologic forms	Total	Resistant to both forms		
			Total	Free-threshing	
				80% plus	90% plus
Khapli x Mindum, F_3	9 and 17	125	24	11	2
Khapli x Mindum, F_3	9 and 19	133	15	8	2
Khapli x Mindum, F_3	21 and 34	115	8	4	1
Khapli x Mindum, F_3	34 and 17	44	16	6	1
Marquis Preston } x Mindum, F_4	1 and 18	15[a]	1	—	—

[a] Common-wheat selections.

Both characters studied, *viz.*, rust reaction and free-threshing percentage, appear to be governed by several genetic factors. Between 15 and 20% of the F_3 lines are resistant to the two physiologic forms to which the Khapli parent is resistant. Several of these lines closely resembled Khapli, especially in regard to the retention of the kernels within the glumes after threshing. Approximately one-half of the lines that were resistant to both forms of rust, however, had threshing characteristics which approached those of the durum parent. A few homozygous lines were obtained which were equal to Mindum in the threshing character and which also approached the resistance of Khapli in the field to a large number of forms.

A study of 14 F_4 lines (10) selected from the progeny of crosses between Marquis and Preston and Mindum demonstrated that the resistance of the durum parent could be combined with the common type of head of the Marquis parent (Table 2). A number of characters, such as type, dwarfness, seed color, awns, and seed length (6, 7, 9), have been studied in relation to rust reaction of other crosses and in no case were there such linkages as to make impossible the combination of the morphological or agronomically desirable characters with resistance to particular physiologic forms.

It already has been mentioned that Khapli, an early variety of *T. dicoccum*, is resistant to all physiologic forms of wheat stem rust yet found in this country. The high degree of self-sterility in the F_1 hybrids of crosses between Khapli emmer and common wheats has led to the practical failure of Khapli emmer-common wheat crosses (8). Because of this failure Khapli has been crossed with Mindum, a durum variety. In the F_2 generation the durum segregates were selected and crossed with Marquis. From this second cross promising selections were obtained which are rust resistant. From cytological studies made by Dr. Griffee certain of these selections were found to have 21 pairs of chromosomes. Some typical but completely susceptible emmers also were obtained, which demonstrates the transfer of susceptibility from the common parent to segregates of the emmer type.

Earlier in this discussion attention was called to the possibility that the reaction of each physiologic form of stem rust might be governed by a seperate pair of independently inherited factors. Evidence has been obtained to show that there may be one or several factor pairs in the host which govern the reaction to a single physiologic form. On the other hand, one factor pair may govern the reaction to several physiologic forms. In a cross between Marquis and Kanred a single factor pair governed the reaction to 11 different forms of stem rust (1). A summary of the results obtained from several crosses is given in Table 3.

In some cases the segregation for type of reaction is not clearly defined and it is difficult to determine the exact number of factor pairs directly concerned. In such cases the presence of several factor pairs and modifying factors usually was quite evident. The individuality of the different forms as separate genetic entities is illustrated in the Mindum x Pentad cross where the reaction of the progeny to Form 1 is governed by a single factor pair and to Form 34 by several factor pairs. The dominance or recessiveness of the different reaction types in the segregating generations, as summarized in Table 3, may be placed in three groups. In the first group, immunity (type 0) dominates both resistance and susceptibility (types 2, 3, and 4). In the second group, susceptibility (type 3 or 4) dominates resistance (type 1 or 2). In the third group, an exception to the second, the resistance of Khapli (type 1) dominates the susceptibility of Mindum (type 4).

The results presented thus far have been primarily drawn from studies made on seedling plants under controlled greenhouse conditions following inoculation with pure cultures of the various physiologic forms of stem rust. Such studies were necessary to the determination of fundamental facts in the inheritance of resistance to stem rust. The reaction to particular physiologic forms shown by seedling plants grown in the greenhouse may not necessarily be a criterion of the reaction in the field (1, 8, 9, 18). The field epidemic, as a rule, would be caused by several physiologic forms of stem rust. At present it is impossible to differentiate the plants for their reaction to particular forms under a general field epidemic. If a variety of wheat is resistant to all physiologic forms in the greenhouse, it also will be resistant in the field, as is evidenced by the varieties Khapli emmer (18) and Webster (20). Kota, moderately susceptible to most forms in the greenhouse, is fairly resistant in the field. Marquillo is resistant to some forms in the greenhouse and susceptible to others, while in the field it is quite resistant to all of these same forms. A selection from Velvet Don, which is a variety of durum wheat, has been highly resistant in the rust nursery for the last 18 years. During the winter of 1925 this variety was inoculated, in the seedling stage, in the greenhouse, with 11 physiologic forms of stem rust.[5] It was highly susceptible to all of the forms (Table 4). The following summer, 1926, the rust epidemic in the field was produced by spraying with most all of these same forms. Velvet Don showed only a trace of rust, with a resistant type of pustule, while the checks were heavily infected. A common-wheat selection made by McFadden (11) from a cross between Vernal emmer and Marquis was highly resistant in the field, and also was highly resistant in the greenhouse to 10 of the physiologic forms, but was susceptible to Form 21

[5] Inoculation studies with Velvet Don and Marquis x Emmer were made jointly with Dr. M. N. Levine and F. J. Stevenson.

TABLE 3.—*Summary of the reaction of parents and hybrids of several wheat crosses to different physiologic forms of Puccinia graminis tritici.*

Physiologic form	Parents						Hybrids		
							Dominant		Number of factors
	Variety	Reaction class	Infection type	Variety	Reaction class	Infection type	Reaction class	Infection type	
1, 9, 17, 21, 29, 37	Marquis	Susceptible	4	Kanred	Immune	0	Immune	0	One
1	Kota	Susceptible	3	Kanred	Immune	0	Immune	0	One
27	Marquis	Resistant	2	Kota	Immune	0	Immune	0	Two
19	Marquis	Resistant	2	Kota	Susceptible	3	Susceptible	3	Several
19	Marquis	Resistant	2	Mindum	Susceptible	4	Susceptible	4	One plus modifiers
1	Marquis	Susceptible	4	Mindum	Resistant	1	Susceptible	4	Several
34	Kubanka No. 8	Susceptible	3	Pentad	Resistant	1	Susceptible	3	Two
1	Mindum	Resistant	1	Pentad	Susceptible	4	Susceptible	4	One
34	Mindum	Susceptible	4	Pentad	Resistant	1	Susceptible	4	Several
9, 17, 19, 21, 34	Mindum	Susceptible	4	Khapli	Resistant	1	Resistant	0 to 2	Several

(Table 4). Isolated plats of this variety were grown in three places and sprayed heavily several times during the summer with a suspension of urediniospores of physiologic form 21. It seemed to exhibit the same reaction phenomenon to this particular rust form as Velvet Don did to all 11 forms. It was highly resistant at all places in the field.

Several wheats, moderately to highly resistant in the field, were studied on several occasions (18, 20, 21) for their reaction in the seedling stage to particular physiologic forms in the greenhouse. These same varieties were then grown in the field under an artificial epidemic of rust produced by spraying the plants with the same forms with which they were inoculated in the greenhouse. A comparison of the relative rust reactions of several of these varieties in the greenhouse and field can be made from the data given in Table 4.

From these results it is evident that the reaction of the seedlings in the greenhouse to particular forms can not always be taken as a criterion of the field reaction. Marquillo, Kota, G40, G149, and Webster are all moderately resistant in the field, whereas the seedling reactions in the greenhouse to these particular forms vary from susceptibility to resistance.

TABLE 4.—*A comparison of the seedling reaction of several wheat varieties in the greenhouse to certain physiologic forms of stem rust with the reaction of fully grown plants in the field when grown under an artificial epidemic induced by these same forms.*

Variety	Rust reaction in the Greenhouse to physiologic form[a]								Field
	1	3	9	17	18	19	21	36	
Marquis	S	S	S	S	S	R	S	S	S
Marquillo	R and X	S and X	R	S and X	S and X	R	R	R	MR
Kota	MS	MS	MS	MS	S	MS	MS	S	MR
Webster	MR	MR	MR	MR	MR	R	MR	MR	MR
H 44	R	R	—	—	R	R	S	—	R
G 40	MR	—	MS	R	MR	MR	MS	MS	MR
G 149	MR	MR	R	R	MR	MR	MR	MR	MR
Velvet Don	S	S	—	—	S	S	S	—	R

[a]Explanation of symbols: R, resistant; MR, moderately resistant; MS, moderately susceptible; S, susceptible; X, indeterminate.

Immunity or a high type of resistance can be differentiated in the seedling stage in the greenhouse with the expectation that the strains probably also will be resistant in the field. Moderate resistance, however, must be differentiated under field conditions in order to have an accurate determination of the reaction of the plant. For determining this type of resistance, breeding studies must be carried on in the field and the selections made from plants grown under an epidemic of stem rust induced by all the physiologic forms present in the area in which the variety is to be grown.

Two methods have been used in the field to insure, so far as possible, the opportunity for all varieties to come in contact with all of the physiologic forms. An artificial epidemic of stem rust is produced in the breeding plats by spraying the plants with a spore suspension of urediniospores and by transplanting cultures of rusted wheat to the field. This is supplemented with material collected in areas in which natural epidemics occur. The rust spores from such collections are used either to dust or spray the plants in the rust nursery. The second method consists of growing the promising new productions at various stations in the regions in which they are expected to be grown later. In the first method the parasite is brought to the host plants in the breeding plats, while in the second method the selections are taken out and exposed to the natural epidemics of rust in the field.

DISCUSSION

A crop-improvement program concerned with disease resistance must take into consideration the possibility of physiologic forms of the pathogenic organism. A survey is necessary in order to determine the prevalence and distribution of the pathogene. If physiologic forms are found to be present, it is essential to determine the reaction of the crop varieties to each particular form. The demonstration of the reaction of the varieties to particular physiologic forms can be carried on best in the greenhouse under controlled conditions. The reaction to all forms in the field is of primary importance to the breeding studies. Therefore, studies must be conducted in the field under conditions of an artificial epidemic.

By means of crosses between the varieties which show resistance to particular physiologic forms, resistance to all forms may be recombined in a single variety. The extent of the crosses resorted to in an effort to produce synthetically the desired recombinations of characters is illustrated in the following diagram which is a pedigree of one of the crosses now being studied.

1. Marquis 2. Iumillo	5. Marquillo	8. First double cross	F_1 Cross
Marquis 3. Kanred	6. Hybrid 11–17–40		
Marquis 4. Vernal (emmer)	7. Hybrid H44		

It will be noted that eight standard or hybrid varieties have entered into this pedigree.

Combining the resistance to all forms of the pathogenic organism within a single variety by no means completes the problem. A new variety of wheat must be desirable in other respects, such as high-yielding ability, stiff straw, early maturity, and good milling and baking qualities. It should not be susceptible to other diseases to the extent that such susceptibility may be a limiting factor in production. A rust-resistant variety of wheat, resistant also to such destructive diseases as bunt, loose smut, orange leaf rust, foot rots, scab, etc., is much more likely to produce a successful crop than one which is susceptible. The multiplicity of problems which must be solved in producing a new variety of wheat necessitates cooperation in many related fields of study. Specialists in genetics, plant pathology, plant physiology, and cytology usually are needed to investigate particular phases of the problem.

CONCLUSIONS

1. Crop improvement which is concerned with disease resistance must take into consideration: (a) The possible existence of physiologic forms of the pathogenic organism, (b) the need of a survey to determine the prevalence and distribution of the various forms, (c) the varietal reactions of the host to particular forms, (d) the reactions between host and parasite as definite genetic characters, and (e) the possibility of combining the resistance to all forms within a single desirable commercial variety.

2. Studies of species crosses have demonstrated that resistance to stem rust can be transferred from the durums and emmers to common wheats.

3. A greenhouse test is necessary to determine the mode of inheritance of the reaction of a variety or hybrid to particular physiologic forms. A field test is necessary in order more fully and accurately to determine varietal reaction to rust under the particular environmental conditions where the variety is to be grown.

4. Genetic evidence has been obtained regarding the mode of inheritance of resistance in wheat to many physiologic forms of stem rust. This evidence, as well as that from extensive breeding studies conducted under field conditions, substantiates the belief that it is entirely possible to produce a bread wheat resistant to all of the known physiologic forms of stem rust. Some varieties with fairly high rust resistance and of good milling quality are already available. Better and more highly rust-resistant varieties probably can be obtained eventually.

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3. BREEDING PLANTS FOR DISEASE RESISTANCE[1]

C. E. Leighty[2]

The control of plant diseases by means of immunity inherent in the plants themselves is one of the most alluring propositions in agricultural science, and breeding for disease resistance is one of the most attractive fields of work. With apparent disregard of the effect on the plant pathologist of the ultimate control of all diseases by means of immunization, breeding operations with this end in view appear to be proceeding with increasing momentum. One can scarcely name a disease-afflicted crop for which amelioration is not being sought through breeding operations directed toward the development of disease-resistant varieties.

Very much of the increased interest in breeding for disease resistance is doubtless due to better understanding of the diseases themselves. Very important in this better understanding of diseases are the discoveries that have been made in respect to physiologic forms of several important diseases. Considering rusts alone, at least 37 physiologic forms of stem rust of wheat and 12 forms of leaf rust are known. Four physiologic forms have been isolated in the rust of corn, two in the leaf rust of rye, and two in the leaf rust of barley. In several other diseases of different plants two or more distinct biologic forms are known.

The discovery of physiologic forms has tended to explain some of the aberrant results in earlier breeding operations. A disease-resistant strain sometimes was found to succumb to disease in certain years or when grown in a different locality. Explanations sometimes were offered that this was due to the effects of different environments. As the matter is now understood, it was often due to the presence of different physiologic forms of the disease to which the supposedly resistant strain was susceptible.

While the discovery of physiologic forms in pathogenic organisms has tended to clarify the problem, it has made it even more complex, at least from a psychological standpoint. Whereas in earlier days breeding was being done for resistance to a disease that was considered due to a single definite organism, today we are dealing with what amounts to an indefinite number of organisms. Resistant selections are found to be only partially resistant; or if they are resistant to all known forms of the disease-producing organism, we are constantly haunted by the fear that a new form will be discovered to which the otherwise resistant strain is susceptible. The writer knows something of this from his personal experience. It was his good fortune to develop a strain of wheat, Hussar, which was found by others to be immune to bunt. Year after year it was grown under conditions most favorable for bunt infection, from seed plentifully covered with bunt spores, without being in the least infected by the bunt fungus. Recently, however, when grown in Germany, it was heavily bunted by the form of bunt organism present in that country. Since then these results have been confirmed by use of spores of this German form in experiments in this country. Other strains of wheat immune from the American form of bunt are likewise susceptible to the German form.

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[1] Discussion of paper by O. S. Aamodt on "Breeding Wheat for Resistance to Physiologic Forms of Stem Rust," presented at the meeting of the Society held in Washington, D. C., November 19, 1926.

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In addition to the ever-present danger of the introduction of new forms of disease-producing organisms from other localities, there exists a possibility of changes in the disease organisms already present in any locality, rendering them capable of infecting resistant strains. Several experiments have indicated that a physiologic form is constant in its behavior and that there is little danger of changes occurring in it that will make it more virulent or capable of wider pathogenicity. Some recent results by several workers, however, are rather disturbing. These show that changes in pure cultures of several species of fungi may occur rather frequently. Leonian, in his work on *Fusarium*, has found that mutations occur in single spore cultures grown under identical conditions. These mutations appear regardless of outside conditions and affect the general appearance, physiology, and morphology. They appear and behave as different species in different phases of the life cycle. Leonian (6)[3] has also found mutations occurring in the rhubarb *Phytophthora*. In a recent paper he describes five types arising from a single sporangium. Three of these breed true and two are described as reversible mutations. These mutated lines are so unlike each other that colonies grown under identical conditions would hardly be taken for the same species.

Christensen (2) has observed mutation with physiological specialization in *Helminthosporium*. Other mutations in fungi have also been recently observed by several others. These results indicate that disease organisms may be able to adapt themselves in such a way as to enable them to infect resistant strains. If this is the case and the process is continuous, then immunity will be only temporary, and breeding for resistance must proceed step by step with the disease.

[3] Reference by number is to "Literature Cited," p. 224.

Another danger in connection with the pathogenicity of disease organisms is the possibility that new forms of diseases may arise through union of different physiologic forms or even species of certain organisms. This might result from the coalescence of the mycelia of two different organisms present in the tissues of a plant. That this possibility is not entirely visionary would appear from the observations recently made by Tisdale, Melchers, and Clemmer (10), who have found a kernel smut on milo and hegari, two hitherto immune varieties. This smut, although generally more like *Sphacelotheca sorghi*, often has characteristics, both macroscopic and microscopic, which are typical of *S. cruenta*. Tisdale has suggested in personal conference that there is a possibility that the two species of kernel smut growing in the same plant have fused and that the highly pathogenic form on milo is a hybrid between them.

The data presented in the preceding paper by Aamodt from results obtained in breeding for resistance to stem rust are similar in many respects to results obtained by Mains, Leighty, and Johnston (8) in studies of the leaf rust of wheat. It has been found that at least 12 different physiologic forms of leaf rust are in existence. These forms are differentiated by the reaction of certain hosts. By crossing the differential hosts the inheritance of resistance and susceptibility has been determined. It has been shown that the resistance possessed by one parent and the susceptibility possessed by the other segregate in F_2 always in approximately a 3 to 1 ratio. Resistance is sometimes dominant, and sometimes susceptibility is dominant. With Malakoff as one of the parental varieties, used in many crosses, dominance or recessiveness of resistance agreed with the reaction of Malakoff to the form of rust being used. That is, if Malakoff was susceptible to the particular form, then susceptibility showed dominance; if Malakoff was resistant then resistance was dominant.

If differential wheat hosts of leaf rust are crossed and two different forms of leaf rust to which the parents are reciprocally susceptible and resistant are used successively to inoculate F_2 plants, it is found that segregation occurs in a dihybrid ratio. This indicates that the resistances and susceptibilities are due to two allelomorphic pairs of factors that are independently inherited.

In the case of leaf rust, as in stem rust, it has been possible to combine in a single individual the resistance possessed by the two parents of a cross. It seems possible that a segregate resistant to all known forms of leaf rust can be obtained by combination of the proper parental individuals.

The reaction toward stem rust of such a strain of wheat resistant to all forms of leaf rust probably would depend upon the reaction of the parental plants. Resistance to leaf rust does no necessarily mean resistance to stem rust or to other disease-producing fungi. It has not been found that the quality of resistance to one pathogene necessarily carries with it resistance to any other pathogene, although there is evidence that reaction to several physiologic forms may be governed by a single pair of factors. A variety of wheat resistant to certain forms of stem rust may be very susceptible to certain forms of leaf rust, and may also be very susceptible to scab and bunt. A variety immune from flag smut may be susceptible to bunt. On the other hand, it has been found that certain strains resistant to one disease are resistant to others also. Mains (7) cites several cases of this kind. Of wheats resistant to forms of leaf rust, Kanred, Webster, and several durums and emmers are resistant also to several forms of stem rust; Hussar is resistant also to bunt and Norka to powdery mildew and possibly scab. Lines of Abruzzes rye are resistant to stem rust and powdery mildew; certain lines of barley to leaf rust and mildew; certain lines of corn to smut and root rot; and a number of red clover selections are resistant to rust and mildew. It is known also that Forward wheat is highly resistant to both flag smut and loose smut.

The results presented by Aamodt, showing that the reaction of the seedling plants grown in the greenhouse to particular forms cannot always be taken as a criterion of the reaction of fully grown plants in the field, recall the results obtained by Mains, Leighty, and Johnston (8) with leaf rust. A cross having a selection of Fulcaster resistant to physiologic form 9 for the resistant parent and Kanred as the susceptible parent was studied in the greenhouse at Manhattan, Kans., in the seedling, shooting, and heading stages. In the seedling stage the F_1 plants were somewhat more resistant than the susceptible parent in its reaction to form 9, while in the shooting and heading stages they were more nearly intermediate in reaction in comparison with the resistant and susceptible parents. Heterozygous plants in the F_2 became progressively more resistant in successive stages of development, while homozygous-resistant and homozygous-susceptible plants maintained resistance and susceptibility, respectively, in all stages. As these plants which changed in their reaction when tested in the F_3 for the most part proved to be heterozygous, and as the F_1 plants also showed somewhat more resistance in later than in earlier stages of development, apparently the interesting situation occurs that heterozygous plants in this cross are indistinguishable in reaction in the young stages from homozygous susceptibles, while in later stages of development they usually can be distinguished by more or less resistance. It may be that other factors are involved, possibly derived from the Kanred parent, although the latter in this particular study showed no evidence of any such resistance.

The question naturally arises as to the nature of disease resistance. Is it due to morphological or to physiological causes? While very little is known about the cause of resistance, it is probable that various morphological and physiological causes are operating and that the quality of resistance is transmitted in inheritance by the transmission of the morphological and physiological factors to which resistance is due.

Tisdale and Tapke (11) found that Nakano Wase barley never produced smutted heads even when grown from seed inoculated with loose smut spores. They found, however, that the seedlings of Nakano Wase were injured as severely as those of susceptible varieties. The fungus penetrated the seedlings of Nakano Wase, evidently beyond the superficial layers, as it did in susceptible varieties, but the surviving plants were smut-free at maturity. This result would follow if the plants of this variety are so sensitive that all infected seedlings are killed. This is hardly likely to have happened, however, and it appears rather that the fungus for some reason is unable to keep pace with the development of the plant, thus leaving the surviving plants smut-free at maturity.

Cytological studies made by Allen (1) on the reaction of Khapli emmer to three forms of stem rust, to all of which Khapli is highly resistant, show that the stomatal guard cells between which the fungus enters, are more or less damaged, probably by secretions of the fungus. The fungus then attacks the mesophyll cells causing them to collapse and die quickly. Other surrounding cells also are killed, forming a damaged zone through which the fungus manages to grow and slowly invade new tissue, although it seldom produces spores. Adjustment between host and fungus fails to occur for some reason not determined. The actual cause for the resistance of Khapli to the rust remains obscure, although ultimately it must be chemical in nature.

Hursh (5) found that on stems of wheat black stem rust grows only in the collenchyma and cannot penetrate the sclerenchyma. The spread of the mycelium is sharply limited if the collenchyma occurs in narrow isolated strands, surrounded by sclerenchyma.

Tisdale (9) studied the causes of resistance of flax to wilt. He concludes that *Fusarium lini*, the causal organism, "penetrates the resistant flax plant and stimulates division and cork-wall formation in cells adjacent to those attacked, but is not able to invade the tissues to any considerable extent." The cork walls that are formed may serve as a barrier to further invasion by the already weakened hyphae. It is also possible that there may be substances in the resistant plant injurious to the fungus, or its protoplasm may be highly sensitive, reacting readily in ways resulting in resistance on invasion.

Dickson and others (3, 4) have found that wheat seedlings grown under favorable conditions are blighted at high temperatures but not at low temperatures, while with corn seedlings conditions are the reverse, corn seedlings being blighted at low temperature and not at high. Chemical studies of these seedlings reveal that, "the relative high content of available carbohydrates in the wheat seedling at the low soil temperatures and the corn seedlings at the high soil temperatures results in thickened cellulose walls offering resistance to fungous penetration. Undoubtedly this difference in chemical composition likewise supplies a different medium for fungous growth when penetration does occur."

In a recent paper Walker (12) shows that yellow and red varieties of onions are resistant to smudge and neck rot, while white varieties are susceptible. He concludes that, "the resistance of colored bulbs to smudge and neck rot is due to a readily soluble substance in the dry outer scales of colored varieties which is toxic to the causal organisms of the diseases concerned. The substance becomes functional by dissolving into the infection drop and inactivating the fungus before penetration can take place."

It appears that disease resistance in plants is due to different causes, most of which are imperfectly understood and many of which are hardly guessed at. Some are apparently morphological and some are physiological or chemical in nature. Greater understanding of the nature of resistance is highly desirable, but in its absence the breeder can proceed with his work by methods already in use.

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4. BREEDING IMPROVED VARIETIES OF FORAGE CROPS[1]

L. E. KIRK[2]

Progress in forage crop improvement has been slow due to the lack of an effective method with plants that are wind- or insect-pollinated. Problems in cereal breeding, being more urgent, naturally were the first to receive the attention of the plant breeders. Also, the mode of pollination of most small grains is such as to assist the investigator in obtaining results in the shortest possible time. Nevertheless forage crops offer many opportunities for improvement. Some of the more important improvements in forage crops which may be mentioned are hardiness combined with high yield of seed in alfalfa and red clover; early, productive varieties of soybeans; a finer stemmed, more leafy type of growth, less objectionable flavor, and better pasture qualities in sweet clover; strains of timothy, brome grass, orchard grass, and other grasses which are better adapted to regional requirements; increased productiveness and disease resistance in all of them.

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Selection has played an important rôle in producing improved varieties of open-pollinated crops. Most of the standard corn varieties in common use are the result of continuous artificial selection. Grimm alfalfa is an excellent example of the effectiveness of natural selection in the improvement of a forage crop. The unaided work of nature must be credited with playing the major rôle in adapting forage crops in general to varied conditions of soil and climate. Selection of the best appearing individuals under open-pollinated conditions, however, is obviously handicapped by lack of control over the male elements in fertilization and has its limitations in loss of vigor and fertility which may accompany too close inbreeding.

The method of inbreeding, now familiar through extensive experiments with corn, provides a mode of attack which seems to promise much for the improvement of cross-pollinated plants. Nearly all of the hay and pasture crops are normally cross-pollinated and are known to consist of a multiplicity of forms among which may be found both desirable and undesirable combinations of characters. If fertile high-yielding strains can be isolated which are homozygous for the factors upon which the more important economic characters depend, it is logical to assume that valuable improvements may be effected. It will also provide a means of studying the mode of inheritance of these characters.

Selection within self-fertilized lines is now being used extensively by plant breeders as a means of obtaining uniform, strong strains of many normally cross-pollinated crops. The effects of inbreeding in the various crops, as reported by different investigators, is of considerable interest. The most obvious effects of inbreeding corn are (a) reduction in size and vigor, (b) increase in uniformity within the selfed line with respect to all characters, and (c) the isolation of undesirable characters including abnormalities of various kinds. Results which substantiate such facts have been published by Shull (25)[3], East and Hayes (3), and East and Jones (4). The work of these and other investigators is familiar to all students of the subject. Thus far no selfed lines have been obtained which are as vigorous as the original variety from which they were obtained.

Herbert-Nilsson (13) and Brewbaker (1) obtained considerable reduction in vigor following self-fertilization of rye. The loss in vigor was most marked in the early generations and very weak strains were discarded during these years. The lines differed widely in fertility. A considerable number of abnormalities were found. Both investigators obtained self-fertilized strains which are as

[3] Reference by number is to "Literature Cited," page 238.

vigorous as commercial varieties and strains have been found which differ in disease resistance, color of seed coat, and other characters.

Nilsson (23) began breeding sugar beets by controlled pollination at Svalöf, Sweden, in 1914. The first really successful isolations were harvested in 1916. The percentage of lines breeding true for morphological characters, or only segregating in one character after the first selfing, was about 45. In general, the selfed lines gave a somewhat lower yield than the standard sorts, but a number of them proved to be as high or higher yielding than the best of the cross-bred varieties. These strains showed no loss in vigor after five generations of selfing. In many hundreds of investigated beet and mangel strains, less than 5% showed signs of so-called degeneration. Fertility was plainly inherited and strains which possessed this character had larger and better developed seed.

Studies in the self-fertility of red clover have been carried on by Fergus (5), Kirk (18), and Williams (26). The number of lines studied has been small because of the difficulty of obtaining selfed seed. Most of the selfed lines showed a marked reduction in vigor. There was much variability in this character, however, and several strains appeared to be quite vigorous after only one or two generations of selfing. Chlorophyll deficiencies were found to occur frequently. A number of strains were secured in the fourth generation which appeared to possess a much greater degree of self-fertility than others.

McRostie (22) and Hamilton (8) have reported work with selfed lines of sunflowers which has been in progress for six or seven years. The general effects of inbreeding were similar to the results observed with corn. Most of the strains were considerably reduced in vigor and after five generations of selfing showed a high degree of uniformity. Several strains were obtained which are just as vigorous as the varieties from which the selfings were made.

Hayes and Barker (10) and Hayes and Clarke (11) have published the results of work with selfed lines of timothy through four or five generations of controlled pollination. The results indicate that timothy does not show nearly as much reduction in vigor as corn or red clover. Strains are produced, many of which are less vigorous and others more vigorous than the best commercial sorts, but in few of them is reduction in vigor very pronounced. Five out of eleven first-year selfed lines of timothy gave albino seedlings in their progeny. Seed-setting under controlled conditions in timothy was shown to be inherited.

Fruergaard (6) worked with selfed lines of turnips (*Brassica campestris*). All of them were less vigorous than the original varieties, being reduced in yield on the average about 30%. On the other hand, rutabagas (*Brassica napus*) gave only 2 out of 35 selfed lines which showed any appreciable decrease in yield as a result of selfing, a fact which was attributed to a high degree of self-fertilization in this crop.

Kearney (16) has artificially self-pollinated cotton for five to seven generations without impairing the vigor or fertility. With cotton, natural self-pollination occurs to a much greater extent than cross-pollination. Data as to the effects of inbreeding vegetables and fruits are very limited, although studies by means of controlled pollination with some of these crops have been started.

Having once obtained selfed lines, the problem arises as to the value of selecting within selfed lines and the value of crossing selfed lines in the production of improved varieties. It is well known that with corn vigor may be regained by crossing. The amount of heterosis appears to depend on the number of favorable growth factors which can be combined in the hybrid, and therefore on the genetic constitution of the parental lines going into the cross. At present, the only way of telling which selfed lines of corn are best as parental material is by the progeny test. It is therefore necessary to make crosses on an extensive scale so as to explore all the possibilities inherent in the selfed lines.

Many single crosses between selfed lines and double crosses between F_1 hybrids have been studied as well as other recombinations. Synthetic varieties, the result of combining several selfed lines, have also been studied. Comprehensive data on the results of crossing selfed lines of corn have been published by Jones and Mangelsdorf (15), Richey and Mayer (24), Kisselbach (17), Hayes (9), and others. In general these studies have shown that hybrids may yield above or below the average of the parental strains and that some hybrids may be secured which yield appreciably above the original varieties from which the selfed lines were obtained.

While it has not thus far been possible to secure selfed lines of corn which are vigorous enough to be used as improved varieties, selfed lines of some other crops have been obtained which do not show such marked reduction in yield. In the cases mentioned above of sugar beets, sunflowers, timothy, turnips, and rye, strong strains have been secured which yield as much as standard varieties. Herbert-Nilsson (13) used vigorous lines of rye to synthesize a variety which is now used on a commercial basis in Sweden. Brewbaker (1) tested eight selected selfed strains of rye in the fifth generation which yielded as much as the original varieties. Hayes and Clarke (11) found selfed lines of timothy which outyielded the standard variety, and McRostie

(22) obtained selfed lines of timothy which outyielded the better open-fertilized strains under test.

Breeding better varieties of any crop is often less a matter of increasing inherent yielding ability under favorable conditions than it is of securing strains that are locally adapted for some special purpose or condition of soil or climate. In localities where drought, cold, insects, or disease may limit production, the ability to survive and produce under such conditions may be the most important consideration in selecting selfed lines. Very marked differences between inbred strains of corn in susceptibility and resistance to corn smut (*Ustilago zeae*) have been reported by Jones (14), Hayes, et al (12), and Garber and Quisenberry (7). Dickson and Holbert (2) found that the seedlings of some self-pollinated lines of corn are able to withstand the attack of root rot (*Gibberella saubinetii*) over a much wider temperature range than others. These differences serve to emphasize the possibilities that may exist for selection within self-fertilized lines. It is evident that selection under diverse environmental conditions is likely to be important, especially with those crops in which vigorous selfed lines can be obtained with a reasonable amount of effort.

FORAGE CROP IMPROVEMENT AT THE UNIVERSITY OF SASKATCHEWAN FIELD HUSBANDRY DEPARTMENT

PRELIMINARY WORK

During the early years, effort was directed mainly toward securing greater hardiness and drought resistance and the method employed was that of continuous selection of cross-pollinated plants. Alfalfa, red clover, and sweet clover were subjected to an intensive process of single plant selection for ten or more years. The results were well worth while, but in many respects progress was slow and success rather indifferent considering the time and labor involved.

The selection work with alfalfa, which preceded the work now being done with inbred strains and which furnished breeding stocks for the latter, may be briefly set forth in the following chronologically tabulated form:

1910. Introduction of hardy strains of alfalfa from many sources.
1911–12. Severe winter killing.
1912. Selection of 1,300 surviving plants as foundation stock.
1913. Clonal propagation of these selections in 10 plant clonal rows.
1915. Selection of 110 of the best clonal rows for further study. Nearly one-half of these traced to Lyman's Grimm and a large proprotion of the balance to S. P. I. 25244 which was received from the United States Department of Agriculture.

1916. Propagation of 110 selections as follows for the purpose of studying further the homozygosity and relative productivity of the strains.
    50 plants of each propagated clonally.
    50 plants of each propagated from self-fertilized seed.
    4 rod rows of each propagated from cross-fertilized seed.

1919. (A) Propagation of nine selected strains in plats of 300 plants each for studying hardiness and yield. Plants spaced 16 inches apart.
(B) Propagation also of each selection in a 40-plant row for observing habit of growth and seed production. Plants spaced 42 inches apart.

1921. Selection of strain number 31.

1922. Comparison for yield of strain No. 31 with Grimm alfalfa in 1/20 acre plats in duplicate and seeding 1 acre for increase in an isolated plat.

1925. Distribution of seed of strain No 31 for testing to members of the Saskatchewan Field Husbandry Association and Experiment Stations. This strain is now designated "Grimm Sask. 666."

This selection project with alfalfa represented a consistent effort to improve the crop. The new strain is superior in hardiness and seed production to the best commercial Grimm under Saskatchewan conditions and equals the latter in yield and quality of forage. It is also more uniform than Grimm alfalfa but still possesses much variability in all characters. The new strain is still under test. It represents the best that it has been possible to accomplish by straight selection methods.

Continuous single-plant selection of red clover has resulted in a strain which is considerably hardier than any of the original stocks, but it has not been demonstrated that the improved strain is appreciably better than the best of them in other respects.

Several hundred selections from eight distinct types of sweet clover have been studied. Greatest improvement has been obtained in the direction of increased hardiness. The selected strains possessed a high degree of uniformity indicating a large amount of self-fertilization.

The breeding work with these crops, including brome grass and slender wheat grass, is now progressing along other lines. Alfalfa and brome grass are being inbred with a veiw to isolating selfed lines that possess a much greater degree of uniformity for the more important economic characters. In addition to making observations on increased uniformity due to selfing, special attention is being given to the effect of selfing on vigor of growth and seed production. The investigations which are in progress with each of the above-mentioned forage crops will be discussed separately and more or less briefly.

ALFALFA

Fourteen of the best clonal rows from the alfalfa selection project described above were used as material from which to obtain self-fertilized lines. This procedure had the advantage of providing superior selected strains with which to begin the new project, strains with which we had become thoroughly familiar. There is considerable advantage also in having several plants to work with rather than the one original plant from which the cuttings were made. The 14 clonal rows were artificially self-pollinated by enclosing heads of unopened flowers in small Kraft paper bags. The bags were manipulated twice. without opening, for the purpose of tripping the flowers. After the pods had set they were torn open and all buds and unfertilized flowers removed. Selfing by this method has always proved quite successful. As a rule much less seed is set in the bags than outside of them, but the quantity of seed obtained by selfing is approximately in proportion to the seed secured from the same strain by open-pollination. In one case, when weather conditions were very unfavorable for pollination, considerably more seed was obtained inside of the bags than from the unbagged heads. Second generation self-fertilized seed was also obtained from several first generation selfed lines from the same original 14 clonal rows. Thus, there was available (a) open-fertilized seed from cuttings of the original plants, (b) first generation selfed seed from the same, and (c) self-fertilized seed from several F_1 plants.

The seed was planted in the greenhouse in 3-inch pots and the seedlings transplanted into the field about June 1st. This nursery consisted of about 5,000 plants and occupied 1.2 acres. The diagram in Fig. 1 illustrates the general plan of the breeding nursery as it appeared in the field.

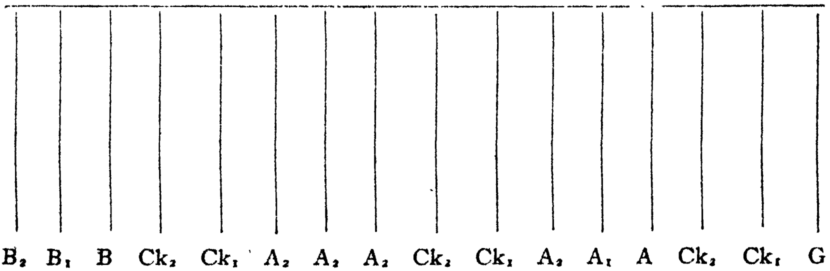
B_2 B_1 B Ck_2 Ck_1 A_2 A_2 A_2 Ck_2 Ck_1 A_2 A_1 A Ck_2 Ck_1 G

FIG. 1.—Diagram of a portion of the alfalfa breeding nursery. Each line represents a row of 40 plants, each plant spaced 42 inches apart each way. G = guard; Ck_1 = check (Grimm); Ck_2 = check (Grimm Sask. 666); A, B, etc. = plants from cross-fertilized seeds of original plant selections; A_1, B_1, etc. = first generation selfed lines; A_2, B_2, etc. = second generation selfed lines.

From Fig. 1 it will be seen that two-thirds of the rows are adjacent to a check and the other rows are only once removed. The double set of checks makes possible a fairly reliable statistical analysis of the yield results. All weighings were made with a Troemer gram scale just as the rows were cut and the weight per plant obtained on the basis of the number of plants harvested.

In 1926, a nursery of third generation selfed lines was planted similar to that described above consisting of about 3,000 plants. Plants from cross-fertilized seed and first generation selfed lines of the original material were included for comparison. Only one cutting from this nursery has yet been obtained.

Table 1 contains the average yields of first, second, and third generation selfed lines of alfalfa expressed in percentage of the yield of plants from cross-fertilized seed. Table 2 gives the average percentage yields for all strains in each generation.

TABLE 1.—*Percentage yields of first, second, and third generation selfed lines of alfalfa.*

Strain No.	Cross-fertilized	First generation selfed	Second generation selfed lines		Third generation selfed lines[a]	
			Mean	Range	Mean	Range
6	100	68	49	43–55	—	—
16	100	73	95	78–111	66	38–91
22	100	76	61	47–74	34	16–49
25	100	82	77	74–80	—	—
31	100	82	87	82–96	27	15–39
32	100	89	61	50–70	—	—
51	100	81	—	—	—	—
54	100	80	62	61–64	48	28–66
62	100	88	64	59–69	57	—
78	100	89	*47	46–47	—	—
86	100	95	*46	31–61	—	—
97	100	70	72	51–85	64	35–90
112	100	89	80	45–118	67	25–100
120	100	75	—	—	—	—

[a] The yields of third generation selfed lines and second generation selfed lines for strains 78 and 86 were obtained from one cutting only. All other yields are an average of three cuttings in two years.

TABLE 2.—*Average percentage yields of alfalfa for all strains in the first, second, and third generations of selfing.*

Generation	Number of strains	Number of cuttings	Percentage yield	
			Mean	Range
Cross-fertilized	14	3	100	
First generation selfed	14	3	81	68–95
Second generation selfed	41	3	72	43–118
Third generation selfed	37	1	53	15–100

Probable errors have been computed on the basis of 24 checks for the average of three cuttings. For Grimm Sask. 666 the probable error was 7.03% and for the standard Grimm variety 9.49%. The average yield for the two series of checks for all cuttings was approximately the same. When these series were correlated, a value of $r=0.74\pm0.09$ was obtained indicating a fairly high correlation between adjacent plats. The results should therefore be interpreted accordingly. The variability in the yield of check plats for the third generation nursery for the one cutting was much larger, giving a probable error of 15.83%.

From the data presented it is evident that inbreeding alfalfa has resulted in a progressive decrease in vigor of growth. A few of the strains, however, are not significantly different in yield from the open-pollinated variety. The third generation results from one cutting are, of course, not strictly comparable with those of the first and second generations from three cuttings. They are strictly comparable so far as first cuttings are concerned because their yields are given in percentage of the cross-fertilized strains which were included in the same test. In order to get an idea of the extent to which a first cutting may be regarded as an index of the yielding power of the different lines, a correlation coefficient was computed for the degree of relationship between the first cutting and the average of three cuttings for the 55 first and second generation selfed lines. This had a value of $r=0.89\pm0.04$, which indicates that the yields obtained from the first cutting were highly indicative of the productivity of the strains in this experiment.

An examination of the data in Table 1 for the separate generations brings out some interesting features with respect to the different selfed lines. First generation selfed lines are reduced in yield on the average 19%. The yield is less for every strain, the loss in vigor varying from 5% to 32%. The second generation selfed lines are much more variable in this respect than the first generation. In strains Nos. 16 and 31 every second generation selfed line has as high a yield as the corresponding first generation and in the majority of cases it is higher. On the other hand, all of the second generation lines in strains Nos. 54, 62, 78, and 86 are very much reduced in yield. It is in the third generation of selfing that the greatest loss in vigor has taken place. All of the strain have produced some weak progeny and a few of them, notably strains Nos. 16, 97, and 112, have one or more relatively vigorous lines. With the exception of strain No. 31, these are precisely the ones that have the highest mean yield in the second generation. Strain 31 was the most consistent high yielder in the second generation and also the most consistent low yielder in the third generation. The results indicate that alfalfa plants of commercial varieties are highly heterozygous.

A study was also made of the relative seed production of the selfed lines. The seed was harvested from 10 consecutive plants in each of the 118 row plats, all of the pods being picked by hand as they matured to avoid possible loss by shattering. The pods were then threshed by hand and the weight of the seed obtained in grams. Table 3 gives the seed yield data for each of the cross-fertilized and first and second generation selfed lines.

TABLE 3.—*Seed yields in grams of first and second generation selfed lines and plants from cross-fertilized seed of the same strain.*

Strain No.	Cross-fertilized	First generation selfed	Second generation selfed lines	
			Mean	Range
6	171	48	25	18–31
16	142	37	45	20–74
22	116	82	35	9–96
25	269	54	48	0–48
31	267	211	67	46–95
32	115	61	14	8–25
54	131	36	26	9–43
62	43	29	17	8–31
97	99	39	33	7–49
112	75	175	64	19–154
51	110	53		
78	76	29		
86	53	49		
120	15	6		
Average first 10 strains	142.8	77.2	37.4	

It is evident that the yield of seed decreased very markedly with each generation of selfing. The data also indicate some correlation for seed setting between the first and second generation selfed lines. A numerical value of $r = 0.46 \pm 0.08$ was found for this relationship when each of the second generation selfed lines was correlated with the corresponding first generation selfed line. The relatively high yield of seed from some of the individual second generation selfed lines seems to afford some justification for thinking that sterility will not be a too serious obstacle in obtaining homozygous inbred strains of alfalfa.

Mention should also be made of the very marked increase in uniformity in the selfed lines. This was most conspicuous in flower color, habit of growth, and quantity and color of foliage, but could be clearly observed in practically all morphological characters. The nursery as a whole presented a striking demonstration of the fact that in a highly heterozygous crop like alfalfa inbreeding tends to isolate types which are as different from each other as the most strongly contrasted varieties.

BROME GRASS

A number of first generation selfed lines of brome grass are being studied for the purpose of isolating desirable forage types. It is expected by inbreeding and selection to eliminate the strongly creeping types and to isolate non-creeping or slightly creeping forms. If these can be obtained, with retention of vigor and fertility, they will be a valuable contribution to the hay and pasture crops of the Northwest. The indications are that this will be possible. Even in first generation selfed lines marked uniformity for desirable characters, including the non-creeping habit, has already been secured.

The method used for selfing brome grass plants is to enclose the entire plant in a cotton cage[4] aproximately 5½ feet high and 3½ feet square. Cotton sheeting of a rather close weave, 54 threads to the inch, is used. The bottom of the cotton cage is soaked in oil and buried a few inches in the soil and the tops kept tightly tied. It is probable that pollen is not absolutely excluded, but it is believed that the method is highly effective in preventing cross-pollination.

A study was made of the relationship for seed setting under controlled pollination between the original plants which were selfed in 1924 and their progeny, consisting in all of 85 plants which were selfed in 1926 The number of seed obtained was expressed as a percentage of the number of fertile florets. For purposes of correlation the seed yield of the progeny of each plant was averaged. A value of $r = 0.55 \pm 0.11$ was obtained, indicating a rather marked inherited tendency with respect to this character.

SLENDER WHEAT GRASS

Slender wheat grass (commonly called western rye grass in Canada) is a comparatively easy crop to improve. It belongs to the normally self-pollinated group, so that most of the selections breed true. A large number of diverse forms exist and improvement consists mainly in selecting and propagating desirable types. A replicated test is being conducted of 21 strains representing the best of 150 selections, most of which were obtained in the wild.

[4] The specifications for these cages were kindly supplied by McRostie and Hamilton, Forage Crop Division, Dominion Experimental Farm, Ottawa, Canada.

SWEET CLOVER

Since 1916 several hundred single plant selections of sweet clover have been studied. None of these have proved more desirable for general use in Saskatchewan than strains of Arctic, an early hardy variety increased from a sample of seed sent to us by Prof. N. E. Hansen which he obtained in Siberia while acting as Agricultural Explorer for the United States Department of Agriculture. A very distinct and interesting selection of yellow sweet clover is being tested and increased at present. The agricultural value of this strain has not been fully determined.

Sweet clover presents a large number of varietal differences. When seeded in rows, varieties differ markedly in amount of foliage and habit of growth; but when grown under uniform conditions in plats, little difference was found (21) between several distinct types in coumarin content, leaf percentage, or nutritive value. It is a question whether yield of forage in the second year of growth and yield of seed are not considerations of secondary importance. Most varieties produce satisfactory quantities of seed, and when moisture is available the larger, coarser types tend to yield most. When moisture is the limiting factor all types tend to yield the same. Pronounced differences in varieties have been observed in the first year of growth with respect to productivity, habit of growth, and ability to retain their foliage in the fall, which may prove of considerable importance in the choice of varieties for pasture purposes.

There are many indications that sweet clover varieties possess a high degree of regional adaptation. The type that is best for a given environment may prove of little value under different conditions. By selection of open fertilized plants it is possible to obtain adapted strains and such selections are usually quite uniform. It would appear that greater progress can be made in securing better varieties by working with a wide range of types than by extensive selection within the limits of one or two varieties, or than by simply confining the attention to commercial white or yellow sweet clover. In other words, varieties of sweet clover are relatively uniform and contain as a rule a much narrower range of variability than may be found in the genus Melilotus.

New opportunities in the breeding of sweet clover have presented themselves recently in the form of so-called "aberrant" forms (19, 20). These plants are very different from ordinary sweet clover. They have finer and more numerous stems, a greater precentage of leaf, and they are considerably less bitter in taste. Progeny of the original aberrant selections gave 25 to 50% of sweet clover segregates, while inbred lines have only 1 to 5%. There is considerable sterility, but most of the aberrant segregates are fully fertile. These aberrant sweet clover plants are both interesting and promising from a breeding standpoint.

SUMMARY

1. Selection within self-fertilized lines is being used for the improvement of many of the normally cross-pollinated crops. In general, reduced vigor and increased uniformity within selfed lines appear to accompany inbreeding in practically all of the crops studied. The occurrence of abnormalities are met with in greater or less frequency depending upon the crop. The selfed lines of some crops behave very much like corn, while others exhibit, on the average, much less reduction in vigor and strains are obtained which yield as much as the original open-pollinated variety.

2. Alfalfa was inbred for three generations, and the selfed lines compared. The yield results show, on an average, a pronounced and progressive reduction in vigor for each generation. A few of the second and third generation selfed lines were not significantly different in yield from the corresponding open-pollinated strains from which they were obtained. The mean yield of seed for first and for second generation selfed lines also showed a marked reduction. A few second generation lines produced seed in relatively large amounts. A correlation coefficient of $r = 0.46 \pm 00.48$ was obtained for the relationship of seed setting between first and second generation lines.

3. Selfed lines of brome grass are being studied with a view to isolating desirable forage types. These exhibit many differences and suggest the possibility of obtaining valuable improvements in this crop. Elimination of the strongly creeping habit is especially desired and the indications are that this will be possible. A correlation coefficient of $r = 0.55 \pm 0.11$ was obtained for the relationship of percentage of possible seed setting between selected plants and their progeny under controlled pollination.

4. Slender wheat grass, being normally self-fertilized, is a relatively easy crop to improve. A large number of distinct types exist some of which are much more valuable than others from a forage standpoint. Superior strains have been isolated and these are being compared for yield and several other characters.

5. Several hundred selections from distinct varietal types of biennial sweet clover have been studied. Highly adapted strains have been obtained by selection. Some new types of sweet clover have been discovered which are promising from a breeding standpoint.

6. The conclusion seems justified that controlled pollination with selection of the more desirable selfed lines is the most promising mode of attack for the improvement of normally cross-fertilized crops after adapted varieties have been obtained.

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5. PROGRESS AND POSSIBILITIES IN FORAGE CROP IMPROVEMENT[1]

P C. Mangelsdorf[2]

Forage crop improvement in the past has been largely a matter of plant introduction and the meager contributions of the plant breeder have been almost completely eclipsed by the remarkable achievements of the agricultural explorer. Although plant introduction is obviously the first step in any program of crop improvement, and although, as Piper has pointed out, this field is far from exhausted, it now seems fairly certain that many of our important forage crops will never be replaced by newly discovered foreign species. In such crops, improvement must be sought through breeding methods and it is gratifying to learn of the excellent work with various forage crops now under way at a number of stations. Professor Kirk's account[3] of the experience at Saskatchewan furnishes a good example of the new interest and new trend in forage crop breeding.

A survey of the literature and correspondence with experiment station workers has led to the following generalizations regarding the present status of forage crop improvement:

1. Continuous selection has not been conspicuously successful in the improvement of cross-pollinated forage crops.

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[1] Discussion of the Paper by L. E. Kirk on "Breeding Improved Varieties of Forage Crops" presented at the meeting of the Society held in Washington, D. C., November 19, 1926.

[2] Assistant Geneticist, Connecticut Agricultural Experiment Station, New Haven, Conn.

[3] See preceding paper.

2. The present trend is toward selection in self-fertilized lines.
3. Hybridization has not played the part which it deserves in the breeding work with forage crops.
4. A wider knowledge of the genetics of important forage crops is needed.

RELATIVE FAILURE OF CONTINUOUS SELECTION

Although a number of experiment stations in this country and abroad have practiced selection in various forage crops, reports of conspicuous improvement are decidedly meager, though not entirely lacking.

Bain and Essary produced a variety of red clover resistant to anthracnose which, though it appears to have had merit for certain sections, has never been widely adopted. Spragg, after 13 years of plant-to-row selection, introduced Hardigan alfalfa which apparently excells other varieties under Michigan conditions. Kirk mentions improvement in certain respects in sweet clover, red clover, and alfalfa. But the important point is that, so far, continuous selection has not produced anything sufficiently superior to replace older varieties to any appreciable extent. Unless a new variety shows outstanding superiority, it is difficult, especially with forage crops, to secure its widespread adoption, and it is a question whether continuous selection in open-pollinated material will bring about sufficient improvement to accomplish this purpose.

SELECTION IN SELF-FERTILIZED LINES

It is encouraging, therefore, to see the present trend toward selection in self-fertilized lines. At some station in this country or abroad, practically every naturally cross-pollinated crop from sunflowers to sugar cane is being forced to undergo the effects of inbreeding, once thought to be so disastrous. Even such crops as red clover and sugar beets, generally classed as self-sterile, are responding to this method of attack.

This trend toward selection in self-fertilized lines represents, theoretically at least, a marked advance in methods and should result in the isolation of superior germ-plasm in many of the most important crop plants. Whether or not this superior heredity can be utilized is another question and one which will need to be answered separately for each crop.

There are, it seems to the writer, only two ways in which inbred strains of forage crops can be used. The strains must either be vigorous enough to replace as pure lines the heterogeneous varieties now grown, or a number of inbred strains must be re-combined into a new and permanent synthetic variety. Single or boudle crosses which give such excellent results in corn are wholly out of the question.

In some crops it seems to be possible to isolate uniform inbred strains which are more productive than the stocks from which they originate. Such strains have now been reported in sunflowers, sugar beets, and timothy. When this fortunate situation is encountered, the breeding problem becomes relatively simple; merely a matter of identifying the best pure lines and increasing them.

In some crops, on the other hand, it seems probable that high-yielding inbred strains may never be encountered, or only so rarely that a systematic search for them is not justified. In corn, where inbreeding has been practiced on a most extensive scale, thousands of inbred strains have been under observation and, so far, no lines superior to the original variety have been definitely established. Probably the same situation will be encountered in other crops as well. Kirk's first and second generation lines of alfalfa all indicate a general decline in productiveness with additional inbreeding. In crops such as these the permanent recombination of a number of inbred strains seems to be the only solution.

Though there are very few data to prove that synthetic varieties will be more productive than the original stocks, there is every reason to believe that they will be, and the preliminary results obtained by Wiggans and by Kiesselbach with corn are favorable. The problem of ascertaining how many inbred strains should be combined and determining whether some strains are better for this purpose than others is one in which the results from corn may be directly applicable to forage crops.

There is one other possibility which is at least worth mentioning. In some crops the yield may be greatly influenced by certain morphological or physiological characters which are inherited in a fairly simple manner, depending perhaps on one or two pairs of Mendelian factors. If such a condition exists, a few generations of inbreeding might result in superior strains merely through the attainment of uniformity with respect to these important characters.

Perhaps the improved strains of timothy developed at Svalöf and at Cornell University may be explained on this basis. Desirable individual plants were increased by asexual propagation and the clonal selections were grown in isolated plats. Interpollination between the plants of the same clone is essentially the same as self-pollination and may result in uniformity for certain important characteristics, particularly disease resistance, which enable the selected strain to excell the original variety.

The possibility of obtaining in other crops slightly inbred strains which are homozygous for certain desirable characters but still heterozygous for a large proportion of the remaining hypothetical growth factors which make for vigor and productiveness is not one to be overlooked.

HYBRIDIZATION IN FORAGE CROP IMPROVEMENT

Hybridization, which has played such an important part in the breeding of many crops, particularly horticultural plants, has contributed almost nothing to forage improvement. Some of our forage varieties have undoubtedly had a hybrid origin. Grimm alfalfa, for example, is believed to have originated from a natural cross between *Medicago sativa* and *Medicago falcata*.

The systematic hybridization of these two species merits a thorough investigation. They are readily crossed and both possess valuable characters which might well be combined. Although *falcata* has been known in this country since 1897 and its value for hybridization has been repeatedly pointed out, not a single new variety has been developed through its use. With the experience of hybridization in other crops as a guide, we should now be in a position to do scientifically what natural selection accomplished accidentally for Wendelin Grimm in producing the variety which bears his name.

Kirk's aberrant sweet clover plants, which certainly appear to be hybrids, with a suggestion of alfalfa ancestry, are very promising. Hybridization of alfalfa and sweet clover is well worth a serious attempt; under certain optimum conditions it may be possible to effect this cross. The possibilities of improvement offered by a combination of these two species would justify considerable effort in attempting their hybridization.

GENETICAL RESEARCH IN FORAGE CROPS

The final fact which stands out in regard to the present status of forage crop improvement is our limited knowledge of inheritance in these crops. In the self-fertilized species, such as soybeans and sorghums, some progress has been made, but in most of the cross-fertilized forage plants only sporadic bits of evidence are available. Though thorough analysis of the germ plasm is not always a prerequisite to plant breeding, a wider knowledge of the heredity of any crop should certainly lead to more effective efforts toward its improvement.

6. THE ACCURATE DETERMINATION OF DRY MATTER IN FORAGE CROPS[1]

G. P. McRostie and R. I. Hamilton[2]

Forage crop workers are at a distinct disadvantage compared to cereal workers in the computation of the yields of the crops with which they have to deal in that the whole plant must be used as the basis of comparison rather than the ripened seed. Many and varied are the pitfalls into which one may fall in the determination of even as simple a consideration as the relative amounts of dry matter in the various fodder crops. A few of the variables will be discussed in the present paper.

The first phase of the subject to be discussed, while not as logically falling under the title presented as the phases to be discussed later, is just as germane to the whole question of accurate yield determination. This is the influence of the inclusion of border on the total dry matter content of the plat concerned.

At the Central Experimental Farm, Ottawa, are a large number of strains of western rye grass. These have been planted in a manner that lends itself to a study of border influence. Western rye grass is self-fertilized, consequently the strains are in reality pure lines. The plants comprising the strains reported on were all planted in cold frames and later transplanted to field plats, the spacing in all cases being one plant to each 6-inch square, thus giving the same number of individuals in each plat in the variety test. Table 1 presents the results secured with a few of the strains which differed to a noticeable extent in morphological characteristics.

Table 1.—*Yield per thousand plants (absolute dry weight) of western rye grass strains grown in 1924.*

Strain No.	Outside plants *Grams*	Inside plants *Grams*	Difference of inside plant yield %
6	174.1	147.8	17.79
7	177.9	157.0	13.31
9	240.2	178.6	34.49
11	238.6	183.6	29.95
14	167.7	158.4	5.87
18	191.7	176.7	8.48
28	241.9	180.2	34.23
36	249.2	161.7	54.11

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[1] Paper read as a part of the symposium on "Plant Breeding" at the meeting of the Society held in Washington, D. C., November 19, 1926.

[2] Agrostologist and Assistant Agrostologist, respectively, Dominion Department of Agriculture, Ottawa, Canada.

TABLE 2.—*Yields per acre of cured hay (15% moisture) of red clover grown in 1925.*

Variety	Border included		Border excluded		Border effect	Loss of air-dried leaves
	Tons	*Pounds*	*Tons*	*Pounds*	%	%
Red clover, St. Clet., Que . .	2	469	2	236	4.94	11.45
Red clover, Kenora, Ont.....	3	1,101	3	512	8.89	3.20
Late red clover, Sweden....	3	843	3	464	5.78	4.28
Red clover, Sask...........	3	422	2	1,801	10.14	5.61
Umbria red clover, Italy....		1,495		1,526	5.60	10.82
Venito red clover, Lombardia.		1,850		1,853	3.09	11.99

TABLE 3.—*Yields per acre of cured hay (15% moisture) of alfalfa grown in 1924.*

Variety	Border included		Border excluded		Border effect	Loss of air-dried leaves
	Tons	*Pounds*	*Tons*	*Pounds*	%	%
Alfalfa, Canadian variegated.	2	1,059	2	487	2.25	5.93
Alfalfa, common...........	2	1,112	2	682	8.77	8.15
Alfalfa, Cossack..........	2	914	2	429	10.97	6.66
Medicago falcata.......	2	1,018	2	935	1.39	6.98
Alfalfa, Turkestan.....	1	1,941	1	1,682	6.86	6.80
Alfalfa, Grimm.......	2	30	1	1,905	3.23	8.92

TABLE 4.—*Yields per acre of cured hay (15% moisture) of sweet clover grown in 1925.*

Variety	Border included		Border excluded		Border effect
	Tons	*Pounds*	*Tons*	*Pounds*	%
White sweet clover........	3	752	2	1,794	16.47
Yellow sweet clover.........	2	1,871	2	1,045	16.44
Dwarf sweet clover........	3	1,251	3	453	17.60
Arctic...............	2	92	1	1,616	11.21
Zouave 778...............	2	1,903	2	974	17.91
Grundy County..........	2	1,362	2	876	9.63
Maccor..............	3	1,683	3	532	17.59

It will be observed that the yields of the border plants and the inside plants are reported in separate columns. The border plants in all cases have given an increased yield due to the influence of the 2-foot pathway which surrounded all plats The significant consideration in connection with Table 1 is that the increase in yield differs with the strain under test, thus there is a difference in percentage ranging all the way from 5.87 in the case of strain No. 14 to 54.11 in the case of strain No. 36. Any assumption that border effect was the same for these plants would quite obviously lead to an entirely wrong interpretation of the comparative yield test.

Tables 2, 3, and 4 present similar data secured from comparative test plats of red clover, alfalfa, and sweet clover, respectively. These plats were seeded broadcast and presented a very even stand.

In all three tables the yields are recorded in tons and pounds of cured hay. This figure is calculated on the absolute dry matter plus 15% moisture which is the approximate moisture content of well-cured hay under the climatic conditions at the Central Farm at Ottawa. An examination of these tables will reveal the fact that while there is less variation due to border influence than occurred in the case of the pure line strains of western rye grass, yet the percentage of border effect is in most cases variable enough to lead to incorrect deductions as to the relative merits of the varieties under test if the borders are included in the test.

The second phase of the subject under discussion is the influence of the method of sampling and drying on the resulting amount of dry matter secured. Findings from four methods of sampling and drying that have been tried out at the Central Farm are presented. In all four methods the absolute dry matter content is used as the standard of comparison.

The first method is the field curing of plats until they are assumed to be in the condition of cured hay. Such a method was for years the standard system of arriving at comparative data with plat tests of forage crops. That such a system is open to criticism from the standpoint of possible inaccuracies is quite evident, as it is almost impossible for a person, much less more than one person, to guess correctly at the stage of curing of the various fodder crops at which the moisture content will be identical in the various lots to be compared. The data contained in Table 5 substantiate this statement.

TABLE 5.—*Relative yields, border excluded, of mixtures of grasses and clovers.*[a]

Plat No.	Green yield *Tons*	Green yield *Pounds*	Relative yield	Field-cured hay *Tons*	Field-cured hay *Pounds*	Relative yield	Absolute dry weight *Tons*	Absolute dry weight *Pounds*	Relative yield
27	11	236	74.95	2	588	106.28	2	1,129	94.37
28	12	1,356	85.47	2	1,147	119.61	2	1,483	100.88
29	14	1,105	98.10	2	1,518	128.24	2	1,889	108.35
30	14	1,761	100.31	2	698	109.18	2	1,458	100.42
31	14	1,668	100.00	2	303	100.00	2	1,435	100.00
32	15	280	102.06	2	317	100.32	2	1,510	101.38
33	15	403	102.48	2	212	97.89	2	1,209	95.84
34	17	1,847	120.83	2	674	108.62	2	1,595	102.94
35	17	1,603	120.00	2	533	105.35	2	1,602	103.07
36	13	427	89.08	2	374	101.65	2	1,280	97.15

[a] Yield of plat 31 = 100.

Table 5 presents yields of green material, field-cured hay, and absolute dry matter of a number of representative plats of mixtures of grasses and clovers. The relative yields, based throughout on the yield of plat 31, are also included.

It is quite evident that the relationship of the different lots is considerably changed according to the method of comparison. Thus, plat 28 gave the second highest yield of green material, but fell to ninth place for field-cured hay and came up to sixth place when the absolute dry matter was used as the basis of comparison.

Of the three systems it is obvious that the green yield is the least accurate, although it might detect large differences between plats. Neither the green yield nor the field-cured hay could be relied upon to detect ordinary differences existing between closely allied varieties, strains, or treatments.

The second method tested was that of extracting a representative shrinkage sample at the time of harvesting the plat. This sample was then dried to constant weight, as nearly as could be computed. The percentage loss in moisture of the shrinkage sample was used as the basis for computing the acre yields of cured fodder contained in the plat concerned. This method is quite commonly used by experimenters at the present time and in some cases appears to be associated with a reasonable amount of accuracy. Tables 6, 7, 8, 9, and 10 contain small but representative amounts of data illustrating this method which have been extracted from larger tables compiled in connection with the different crops concerned.

TABLE 6.—*Dry matter in red clover grown in 1924.*

Sample No.	Weight of air-dried material	Additional loss of material due to oven drying	
	Grams	*Grams*	%
40	659.3	64.41	9.77
41	609.8	36.06	5.91
42	602.4	46.49	7.72
43	797.4	47.17	5.92
44	704.0	28.58	4.06
45	750.1	39.92	5.32

TABLE 7.—*Dry matter in timothy grown in 1924.*

Sample No.	Weight of air-dried material	Additional loss of moisture due to oven drying	
	Grams	*Grams*	%
1	962.1	52.16	5.42
2	1,004.7	36.74	3.66
3	915.0	49.67	5.43
6	861.6	53.52	6.21
8	948.4	83.91	8.85
14	879.5	49.44	5.62

TABLE 8.—*Dry matter in hay mixtures grown in 1924.*

Sample No.	Weight of air-dried material	Additional loss of moisture due to oven drying	
	Grams	*Grams*	%
80	973.0	70.31	7.23
81	1,018.0	50.12	4.92
82	952.3	31.98	3.36
83	973.0	68.95	7.09
86	918.3	64.18	6.99
88	822.0	52.84	6.43

TABLE 9.—*Dry matter in corn grown in 1924.*

Sample No.	Weight of air-dried material	Additional loss of material due to oven drying	
	Grams	*Grams*	%
1	342.7	15.65	4.57
22	322.7	16.10	4.99
25	358.6	20.87	5.82
32	443.8	25.17	5.67
37	422.8	31.07	7.35
45	389.2	28.12	7.23

TABLE 10.—*Dry matter in sunflowers grown in 1924.*

Sample No.	Weight of air-dried material	Additional loss of moisture due to oven drying	
	Grams	*Grams*	%
1	245.0	14.97	6.11
2	264.7	91.96	7.54
3	210.8	13.61	6.46
7	275.2	17.24	6.26
12	244.5	24.04	9.83
16	308.0	28.12	9.13

In these tables the additional loss of moisture is figured in terms of percentage of the air-dried weight. The variation in the percentage of additional moisture extracted by oven drying indicates that the moisture content of samples dried to a constant weight may vary to an appreciable extent. It is quite possible that a different method of drying to constant weight might have some effect on the results obtained. Unpublished data from MacDonald College would seem to indicate that when shrinkage samples are oven dried to below moisture content of well-cured fodder and then allowed to stand in a room with a uniform temperature until they have regained constant weight the results are more accurate.

Smaller differences may be detected by the use of this method than where the field-cured hay is used as the basis of comaprison, although a variable factor still exists.

The third and fourth methods of drying may be considered together in as much as the same series of tables will convey the data secured in connection with these methods. In the case of both methods shrinkage samples were extracted at the time of harvesting the plats. In the first case, these samples were air dried sufficiently to keep indefinitely in storage. Later, they were oven dried to an absolute dry weight. In the second case the green shrinkage samples were immediately oven dried to absolute dry weight. Tables 11, 12, 13, and 14 present the data secured.

The data indicate that there is a possibility of variation even when the absolute dry matter is used as the criterion for comparative tests. One fact stands out quite clearly and that is that there appears to be a significant but variable loss of dry matter due to air drying previous to oven drying. The speed of drying also gave evidence of having a direct bearing on the results obtained, as did also the length of time which elapses before the shrinkage sample is oven dried. A recent publication of the University of Oxford[3] records data substantiating these observations. The claim is made that in delayed drying soluble carbohydrates are reduced to insoluble, that volatile oils are lost, and that enzymatic action is responsible for a loss of protein. In any case the loss of dry matter appears to be definite, appreciable, and variable, thus confronting forage crop workers with a further difficulty in the securing of accurate comparative tests.

From the applied standpoint it would appear that the present systems of hay making are accompanied by appreciable losses of dry matter due to delayed drying in addition to the very appreciable loss of leaf due to handling of the fodder. The most careful field handling of hay in the experiments has not been able to reduce the loss of leaf lower than 5%, on the average, while with less careful handling this loss has amounted to as much as 75 to 80% of the total leaf of the plant in a few cases. The experiments which are being carried out both in Europe and on this continent having in view the immediate drying of fodder by artificial means would therefore appear to be well worth the careful consideration of agronomists.

The final phase of the investigations under discussion is the relationship between the size of the shrinkage sample and the accuracy of the results obtained. To arrive at information concerning this problem twelve 2-pound samples were extracted at the time of cutting instead of the customary duplicate samples.

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[3] Preliminary report of an investigation into the artificial drying of crops in the stack. Institute of Agr. Eng., Oxford Univ.. Oxford Univ. Bul. 2: 1-104. 1926.

TABLE 11.—*Dry matter in first cutting of alfalfa grown in 1926.*

Variety	Dried immediately			Air dried previous to oven drying																			
	Sample 1	Sample 2	Average	Sample 3	Sample 4	Average of two samples	Sample 5	Average of three samples	Sample 6	Average of four samples	Sample 7	Average of five samples	Sample 8	Average of six samples	Sample 9	Average of seven samples	Sample 10	Average of eight samples	Sample 11	Average of nine samples	Sample 12	Average of ten samples	Decrease[a]
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
McCannus	27.24	26.85	**27.05**	24.12	25.39	**24.76**	23.43	**24.31**	23.53	**24.12**	23.92	**24.08**	24.21	**24.10**	24.80	**24.20**	25.29	**24.34**	24.60	**24.37**	24.51	**24.38**	**9.87**
Turkestan	27.34	27.24	**27.29**	24.31	24.70	**24.51**	23.63	**24.21**	23.92	**24.14**	23.73	**24.06**	23.73	**24.00**	23.33	**23.91**	23.33	**23.84**	25.39	**24.01**	23.92	**24.00**	**12.06**
Grimm, Lyman	25.78	25.68	**25.73**	23.24	23.73	**23.49**	22.85	**23.27**	24.02	**23.46**	23.04	**23.38**	23.82	**23.45**	23.82	**23.50**	24.02	**23.57**	23.24	**23.53**	22.94	**23.47**	**8.78**
Cossack Rife	23.33	23.73	**23.53**	20.89	21.58	**21.24**	20.60	**21.02**	20.21	**20.82**	20.50	**20.76**	20.80	**20.76**	21.19	**20.82**	20.70	**20.81**	20.31	**20.76**	21.48	**20.83**	**11.47**
Medicago falcata	24.51	24.21	**24.36**	21.09	21.58	**21.34**	21.87	**21.51**	22.16	**21.68**	20.99	**21.54**	21.28	**21.50**	21.48	**21.49**	22.26	**21.59**	21.19	**21.54**	21.58	**21.55**	**11.54**
Grimm, Sutton's	25.29	25.39	**25.34**	22.26	22.16	**22.21**	22.75	**22.39**	22.75	**22.48**	22.26	**22.44**	22.65	**22.47**	22.65	**22.50**	22.46	**22.49**	23.04	**22.55**	22.16	**22.51**	**11.17**

[a] Differences between averages of immediately dried sample and averages of the sample air dried previous to oven drying expressed in percentage of the immediately dried material.

TABLE 12.—*Dry matter in first cutting of sweet clover grown in 1926.*

Variety	Dried immediately			Air dried previous to oven drying																			
	Sample 1	Sample 2	Average	Sample 3	Sample 4	Average of two samples	Sample 5	Average of three samples	Sample 6	Average of four samples	Sample 7	Average of five samples	Sample 8	Average of six samples	Sample 9	Average of seven samples	Sample 10	Average of eight samples	Sample 11	Average of nine samples	Sample 12	Average of ten samples	Decrease[a]
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Yellow sweet clover	20.41	20.41	**20.41**	19.33	18.45	**18.89**	18.35	**18.71**	18.75	**18.72**	17.96	**18.57**	17.67	**18.42**	18.35	**18.41**	19.33	**18.52**	19.23	**18.60**	18.94	**18.64**	**8.67**
Dwarf	20.21	20.11	**20.16**	18.06	17.96	**18.01**	18.94	**18.32**	19.14	**18.53**	18.55	**18.53**	18.06	**18.45**	18.55	**18.47**	18.16	**18.43**	19.23	**18.52**	19.43	**18.61**	**7.69**
Arctic No. 1	21.58	21.48	**21.53**	20.11	19.92	**20.02**	20.01	**20.01**	20.60	**20.16**	20.21	**20.17**	19.72	**20.10**	19.53	**20.01**	19.72	**19.78**	20.01	**19.98**	19.33	**19.92**	**7.48**
Zouave 778	21.19	20.80	**21.00**	19.53	19.14	**19.34**	19.33	**19.33**	19.33	**19.33**	19.43	**19.35**	19.33	**19.35**	19.72	**19.40**	19.72	**19.44**	19.43	**19.44**	18.94	**19.39**	**7.67**
Hubam hybrid	20.80	21.09	**20.95**	19.82	19.23	**19.53**	19.53	**19.53**	18.84	**19.36**	19.72	**19.43**	19.53	**19.45**	19.62	**19.47**	19.72	**19.50**	19.14	**91.46**	19.72	**19.49**	**6.97**
Maccor	20.11	19.62	**19.87**	19.92	18.06	**18.99**	18.94	**18.97**	18.75	**18.92**	18.45	**18.82**	18.65	**18.96**	18.94	**18.82**	18.65	**18.80**	18.65	**18.78**	17.96	**18.70**	**5.89**

[a] Differences between averages of immediately dried sample and averages of the sample air dried previous to oven drying expressed in percentage of the immediately dried material.

TABLE 13.—*Dry matter in first cutting of red clover grown in 1926.*

Variety	Dried immediately			Air drying previous to oven drying																		
	Sample 1	Sample 2	Average	Sample 3	Sample 4	Average of two samples	Sample 5	Average of three samples	Sample 6	Average of four samples	Sample 7	Average of five samples	Sample 8	Average of six samples	Sample 9	Average of seven samples	Sample 10	Average of eight samples	Sample 11	Average of nine samples	Sample 12	Average of ten samples	Decrease[a]
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
English	28.51	28.22	**28.37**	27.44	27.14	**27.29**	27.73	**27.44**	27.83	**27.54**	28.02	**27.63**	27.34	**27.58**	27.73	**27.60**	27.63	**27.61**	27.92	**27.64**	27.83	**27.66**	2.50
C. E. F.	31.83	32.22	**32.03**	20.07	30.66	**30.37**	31.05	**30.59**	30.27	**30.51**	30.95	**30.60**	31.15	**31.69**	27.44	**30.23**	31.73	**30.42**	30.85	**30.46**	31.05	**30.52**	4.71
Giant hybrid	26.95	27.14	**27.05**	23.73	24.12	**23.93**	24.21	**24.02**	25.29	**24.34**	26.17	**24.70**	25.29	**24.80**	25.39	**24.89**	25.58	**24.96**	25.68	**25.05**	25.78	**25.12**	7.13
Swedish	21.28	20.60	**20.94**	18.94	19.62	**19.28**	20.50	**19.69**	19.43	**19.62**	19.62	**19.62**	20.70	**19.47**	20.21	**19.86**	20.60	**19.97**	18.94	**19.84**	19.92	**19.85**	5.21
Medium late Swedish	21.09	20.89	**20.99**	19.92	20.70	**20.31**	20.01	**20.21**	19.43	**20.02**	19.72	**19.96**	20.50	**20.05**	20.41	**20.10**	20.01	**20.09**	20.50	**20.13**	20.21	**20.14**	4.05
2423 Roumania	24.80	25.68	**25.24**	23.14	23.14	**23.14**	21.19	**22.49**	21.28	**22.19**	21.09	**21.97**	20.89	**21.69**	22.46	**21.88**	23.24	**22.05**	23.53	**22.22**	22.26	**22.22**	11.97

[a] Differences between averages of immediately dried sample and averages of the sample air dried previous to oven drying expressed in percentage of the immediately dried material.

TABLE 14.—*Dry matter in sunflowers grown in 1926.*

Variety	Dried immediately			Air dried previous to oven drying																		
	Sample 1	Sample 2	Average	Sample 3	Sample 4	Average of two samples	Sample 5	Average of three samples	Sample 6	Average of four samples	Sample 7	Average of five samples	Sample 8	Average of six samples	Sample 9	Average of seven samples	Sample 10	Average of eight samples	Sample 11	Average of nine samples	Sample 12	Average of ten samples	Decrease[a]
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Mennonite 87	10.85	11.01	**10.93**	10.42	10.50	**10.46**	12.10	**11.01**	11.09	**11.04**	9.72	**10.77**	10.54	**10.73**	8.94	**10.46**	9.02	**10.29**	8.98	**10.15**	8.67	**10.00**	8.51
Mennonite 93	10.42	10.82	**10.62**	10.62	10.97	**10.80**	10.31	**10.63**	10.39	**10.57**	8.98	**10.24**	8.98	**10.01**	8.20	**9.78**	8.67	**8.39**	8.28	**8.38**	8.35	**8.38**	21.09
Mennonite 174	13.82	13.20	**13.51**	14.06	14.37	**14.22**	12.96	**13.80**	13.28	**13.67**	12.26	**13.39**	12.65	**13.26**	12.26	**13.12**	12.26	**13.01**	11.52	**12.85**	12.34	**12.80**	5.26
Ottawa 76, 121	13.51	12.65	**13.08**	10.58	11.09	**10.84**	10.46	**10.71**	11.17	**10.83**	9.68	**10.60**	10.23	**10.54**	9.21	**10.35**	9.21	**10.20**	9.29	**10.10**	10.15	**10.11**	22.71
Ottawa 76, 115	11.60	10.23	**10.92**	9.92	10.97	**10.45**	10.82	**10.57**	11.09	**10.70**	10.31	**10.62**	10.11	**10.54**	9.92	**10.45**	9.14	**10.26**	8.59	**10.10**	8.82	**9.97**	8.70
Ottawa 76, 85	9.53	10.62	**10.08**	10.23	9.84	**10.04**	10.31	**10.13**	10.23	**10.15**	8.98	**9.92**	8.82	**9.74**	8.04	**9.47**	7.89	**9.29**	7.03	**9.04**	7.26	**8.86**	12.10

[a] Differences between averages of immediately dried sample and averages of the sample air dried previous to oven drying expressed in percentage of the immediately dried material.

In the case of sunflowers and corn twelve 5-pound samples were taken. In most instances the cut samples were numbered in the order in which they were weighed, so that it would be possible to check up also any loss of moisture occurring during the short time it took for the weighing operations to be completed. Thus, in Tables 11, 12, 13, and 14, sample 5 was weighed after sample 4, sample 6 after sample 5, etc.

In arriving at conclusions from the data in the afore-mentioned tables only samples 3 to 12, inclusive, should be considered, as they are the ones which have received a common treatment. On the whole, very little variation in the percentage of dry matter can be observed by the inclusion of the additional 2-pound samples to the average of the first two samples extracted. Small differences are apparent between the averages of the duplicate samples and the averages of the 10 samples considered. It is doubtful, however, if there is enough difference to warrant the extra labor of extracting the larger sample or a larger number of individual samples. It would appear that the length of time which elapsed between the extrating of the samples and the oven drying would offer much greater possibilities of variation than would be found within the additional samples thus included.

On the whole, the investigations lead to the following general conclusions.

1. The inclusion of the border foot in plats surrounded by cultivated paths is associated with inaccuracy of result.

2. The use of either green weights or the yield of field-cured hay as a basis of comparison in test plats is unreliable.

3. The practice of computing yields of comparative test plats on the basis of the loss of moisture of shrinkage samples dried to a constant weight, while reliable for the detection of reasonably large differences, still possesses an appreciable variable factor.

4. There is an appreciable and variable loss of dry matter in shrinkage samples held for air drying before being finally oven dried.

5. The immediate drying of shrinkage samples appears to offer the most accurate criterion for comparative tests.

POROUS CLAY AUTO-IRRIGATOR CONES FOR WATERING POTTED SOIL AND PLANTS[1]

E. P. DEATRICK[2]

It has always been a tedious job to keep potted soil watered. The common method of regularly adding water to bring the weight of a pot back to that originally recorded has its disadvantages. The amount of labor involved limits the number of pots one can run. Especially laborious is the task of moving large pots back and forth at short intervals from table to balance. Special apparatus, such as drainage tubes can not easily be attached to pots that have to be thus moved. All pots can not be watered alike. Although pots are brought back to the original weight regularly, those carrying the heaviest crop will have the greatest drying-out and wetting-up in any interval. All of these disadvantages have been overcome in the method here described—a method made possible by the production of the porous clay auto-irrigator cones by Livingston.[3] Although Livingston's paper was published in 1918, only one case has come to the writer's knowledge where these cones have been used for soil work. A preliminary report is therefore being made.

The auto-irrigator cones are made of white porous clay shaped similar to Erlenmeyer flasks of about 200 cc. capacity. The accompanying photograph (Fig. 1) shows an experiment now being run. One hundred and fifty 4-gallon crocks have each been filled with 13 kilograms of air-dry soil. Wheat was planted only a few days before the photograph was taken and hence does not appear. Except when the reserve bottles need changing, the soils are kept at optimium moisture content continuously with but about 15 minutes attention per day.

Livingston states that when a large number of irrigator cones are used "the apparatus functions with relatively very great precision, automatically adding water to the soil about as rapidly as the plant absorbs it, and the soil moisture content fluctuates over a range of only a few per cent. . ."

In Fig. 2 part of the first row of pots only has been sketched together with a supply bottle and the suction system. At several

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[1] Contribution from the Department of Soils, West Virginia Agricultural Experient Station, Morgantown, W. Va. Approved by the Director as Scientific Paper No. 29. Received for publication December 7, 1926.

[2] Associate Professor of Soils.

[3] LIVINGSTON, B. E. Porous clay cones for the auto-irrigation of potted plants. Plant World, 21:202. 1918.

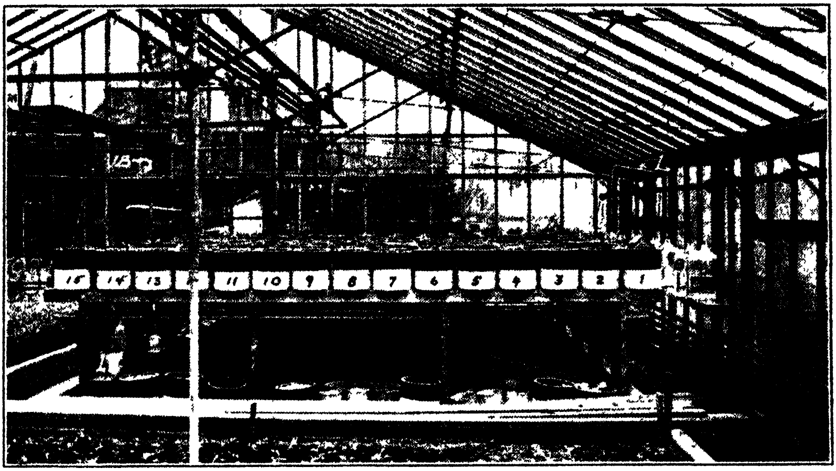
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FIG. 1

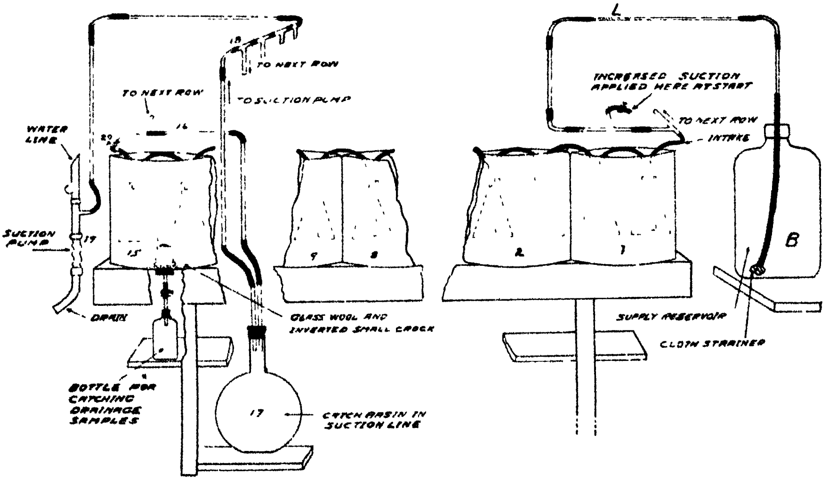
TO NEXT ROW
18
TO NEXT ROW
TO SUCTION PUMP
16
20
WATER LINE
SUCTION PUMP
17
15
9
8
DRAIN
GLASS WOOL AND INVERTED SMALL CROCK
BOTTLE FOR CATCHING DRAINAGE SAMPLES
17
CATCH BASIN IN SUCTION LINE
L
INCREASED SUCTION APPLIED HERE AT START
TO NEXT ROW
INTAKE
2
1
B
SUPPLY RESERVOIR
CLOTH STRAINER

FIG. 2

points the perspective has been changed in order to show the details more clearly. The auto-irrigators have been fitted with long inlet and short outlet glass tubes. The rubber stoppers through which these pass are turned into the cones as tightly as possible. The stoppers and extreme top of the cones were covered with wax to prevent leaks. (It is best to test all cones under water pressure for leaks before imbedding them in soil.) Rubber tubing connects the outlet tube of one cone with the inlet tube of another. The exposed portions of the tubes were painted with a black enamel and short clear tubes were inserted between the pots. The greater part of the water system is therefore in the dark and the development of algae is thus guarded against. The clear tubes between the pots enable one to see when the system is free from air and can be replaced in case algae develop there.

When the soil is to be wetted at the beginning, the reserve bottle (Fig. 2, B) must be raised so that water will fill the cones by gravity. Suction is not effective on account of the amount of air that enters the cones through the air-dry soil. After the soil is wetted the reserve bottle may be lowered. When a reserve bottle is replaced, water can be drawn over through the delivery tube (Fig. 2, L) by suction with the mouth. Suction is then applied at the far end of the row of pots (Fig. 2, 16) until all air is removed from the system. In the experiment there are five double rows of 15 pots in each row. A reserve bottle supplies two rows. The last cone of each row is connected with a suction line (Fig. 2, 18).

The outlet tubes of the last cone (Fig. 2,15) in each double row lead into the top of a catch flask (Fig. 2, 17) which is directly connected with the suction line. Suction is supplied by a 13-inch Richard aspirator attached on the city water line. After the air bubbles have been pulled out of the system and the pinchcock on the outlet tubes of the last cones are closed, the water is drawn from the reserve bottle as the soil withdraws water from the cones. The amount of water in the soil is regulated by the level of the reserve bottle in relation to the level of the cones. If the pots are not raised on tables, as in this experiment, a mercury manometer may be used to control the rate of water pulled from the reserve bottle. The amount of mercury in the manometer may be decreased by providing an outlet tube at the lowest point in the bend of the U-tube. Dustman,[4] by drawing off mercury, thus increased the rate of flow from the supply bottles as the plants increased in size and rate of transpiration.

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[4] DUSTMAN, R. B. Inherent factors related to absorption of mineral elements by plants. Bot. Gaz., 79:233–264. 1925.

As might be expected, the system set up as described allowed some back diffusion of the soil solution into the cones. Especially is this the case when clogging occurred which hindered the free drawing of water from the source. When suction was applied at such times, some of the soil solution was evidently sucked into the cones until the clogging "let go." This can be overcome by not connecting the outlet and inlet tubes of the cones in adjacant pots. It is expected that it will be possible shortly to make a subsequent report on a modification of the apparatus described here in which the system is disconnected between pots and water is drawn from a constant-level reservoir.

HOW SOME CROPS AFFECT SUCCEEDING CROPS[1]

Burt Hartwell[2]

In this paper principal attention will be given to the effects which crops have exhibited under pronounced acid-soil conditions at the Rhode Island Station. Since these particular effects of different crops are not greatly modified by ordinary variations in amounts of fertilizer elements when serving the purpose of nutrients, not of antidotes, we may at once dismiss from our minds those inhibiting effects which are due to the fact that one crop may not have left nitrogen, phosphorus, or potassium in combinations from which they could be secured sufficiently to nourish properly a subsequent crop (Bulletin 176).[3] Inasmuch, then, as we are dealing mostly with the effect of crops under highly acid-soil conditions, it is fitting to recall that such conditions include not only acidity but any active substances which may result from that acidity or be associated with it. We shall especially discuss active aluminum as an example of such a substance (Bulletin 194).

Acidity may be diminished by lime, and aluminum may be made less active by the same substance. Phosphoric acid, however, does not lessen acidity, but does serve as an additional antidote for toxic aluminum. In fact, by practical applications of these two antidotes, deleterious effects of crops on those succeeding them may be largely eliminated. Only slight attention will be given to conditions which have resulted from the optimal use of lime and phosphorus as antidotes.

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[1] Paper read at the meeting of the New England Section held in Boston, Mass., December 4, 1926. Contribution 341 from the Rhode Island Agricultural Experiment Station, Kingston, R. I. Received for publication December 14, 1926.

[2] Director and Agronomist.

[3] Reference in parenthesis is to publications of the R. I. Agr. Exp. Station in each case.

It would be much easier to stick to the assigned subject and tell *how* some crops affect succeeding ones than to explain *why* they exert their specific influence. Nevertheless, even a visionary consideration of certain factors which may influence critical field situations will prove at least suggestive concerning lines of inquiry, and therefore worthy of attention. It is readily confessed before hand that the reasons for the effects in many cases are not known; in fact scarcely any information along certain suggested lines has been ascertained.

Having made certain premises, certain of the factors which may have a bearing on the subject may be discussed, and considered, even if other factors which may prove to be of more consequence are omitted.

Principal attention will be given to soil reaction and its influence on the activity of certain non-fertilizer elements, too much acidity resulting in aluminum toxicity, and too little resulting in manganese deficiency and accompanying chlorosis(Thirty-eighth Annual Report).

The so-called reaction of a soil is frequently measured in terms of H-ion concentration and calcium absorption. When aluminum toxicity is a factor, the activity of this element increases with an increase in acidity, an increase in calcium absorption, and a decrease in available phosphorus.

Since it is the effect of crops and not primarily of soil treatments which is being considered, it is of importance to recognize that crops range between those which are alkaline and those which are acid, because they remove from the soil different ratios of alkaline to acid mineral elements. They also differ in the amount of aluminum and phosphorus which they remove per acre.

With this brief outline in mind certain specific cases of crop effects which have occurred may be considered, together with some of the accompanying determinations which have been made. The first crop which was planted with liberal fertilization, uniformly following 16 different crops in the principal field experiment now being considered, was onions in 1910 (Bulletin 175). The soil was then quite acid; and onions are so sensitive to acid-soil conditions that they were in a very critical circumstance following certain of the crops, the total yield varying from 72, 88, and 99 bushels following mangels, cabbages, and rutabagas, respectively, the three most alkaline of the crops in that they remove in the ash more bases than acids, to 524 bushels following redtop, an acid crop. After corn, another acid crop, the yield was 296 bushels.

The effect of certain crops on soil, at critical points, is measurable in the chemical laboratory. For example, it is stated in Bulletin 175 (page 8) that, "A corn area showed a lime requirement of about 2,600 and a beet area of about 3,500 pounds per acre foot." Again, in Bulletin 198 (page 24) that certain crops, as for example "mangels, increase the acidity (both 'lime requirement' and H-ion concentration) and readily soluble aluminum content of soils; others, like redtop, behave in an opposite manner."

In Bulletin 180 it is recorded that field barley grew less well after beets and carrots than after alfalfa and barley on a quite acid soil, but that there was no difference when the soil had been neutralized. Also, that the relative growth of lettuce in the soil when transferred to pots was as follows: After beets, 16; after carrots, 41; after alfalfa, 78; and after barley, 113. These crop plants are in the same order as when arranged in accordance with their decreasing response to lime added to the soil. However, attention needs to be given to the fact that crops having high lime response are not necessarily those which are the most alkaline, or remove per acre the greatest amount of excess bases.

It is stated on page 11 of Bulletin 186 that, "In case of the unlimed plat, there was a very marked influence of the crops of 1917 on certain of the crops of 1918. For example, on the unlimed soil, onions at the rate of only 92 bushels were produced after the sugar beets; 288, after beans; 319, after onions; and 400, after endive. Whereas, on the adjoining limed plat, the range was only from 485 to 590 bushels."

In the Thirty-sixth Annual Report it is recorded that carrots, corn, mangels, oats, onions, and potatoes were grown crosswise of certain plats in 1922 and lengthwise in 1923. Especially where acid-soil conditions were marked and phosphorus was deficient were the differences in growth very great in some cases, depending upon the crop which preceded. Mangels and corn, for instance, which occupied contiguous areas in 1922, had extremely different effects on some of the crops. Onions yielded three times as much after corn as after mangels, and corn considerably more. Indications were obtained that there was the greatest amount of active aluminum in the areas where growth was poorest.

In Bulletin 198 are recorded some effects of these two crops on the soil, but more especially on the composition of the crops grown subsequently. The lime requirement, H-ion concentration, and easily soluble aluminum of the soil were greater where a crop of mangels had been grown than where a crop of corn had been grown; and, also, in another comparison they were greater where cabbages than where redtop had been grown.

As an illustration of factors possibly pertinent to the subject, it should be recalled that corn is an acid crop; whereas mangels are an alkaline crop, and its removal tends to leave the soil more acid and the aluminum more active.

Furthermore, under the same conditions, corn leaves contained twice as high a percentage of aluminum as did beet leaves. The relatively high percentage of aluminum in corn, and the ability of this crop to make normal growth even where there is considerable active aluminum, point to its value as a remover of aluminum which might otherwise be toxic should the next crop in the rotation prove to be sensitive to it. There was a tendency for the percentage of phosphorus, silicon, iron, and aluminum to be higher when certain crops followed mangels instead of corn; whereas the opposite was true of the more alkaline elements, calcium and magnesium.

It may be of interest to have summarized briefly the later progress of the field experiment involving the influence of 16 crops on different crops. Annual soil tests showed in the early years that the greatest growth responses resulted from applications of lime and phosphorus, both of which are now known to improve acid-soil conditions. Therefore, Thomas slag phosphate was, in the earlier years, used as a prominent annual constituent of the fertilizer; and, as additional alkaline material, 2,500 pounds of calcium oxid in hydrated lime was applied per acre in preparation for the single crop of 1916 and 1917, alsike clover.

The situation was probably no longer critical to alsike clover from the standpoint of acid-soil conditions, the soil test even indicating a depression where more lime was added. The average of the two-year yields of alsike hay ranged from 1.27 tons following alsike clover to 2.17 tons following redtop (Bulletin 175).

In further preparation for a crop highly sensitive to acid-soil conditions, namely, mangels in 1920, not only a ton of limestone was added but also 1.5 tons of wood ashes; with the result that, except where they succeeded themselves, the mangels made a splendid growth following all the crops. The acidity had now all been neutralized and the pH was about 7 in 1921.

The very marked influences of certain preceding crops when onions were grown on the then very acid soil were scarcely noticeable on the equally sensitive mangels, because of the liberal amounts of phosphorus and lime which had been added in the interim (Thirty-third Annual Report). Having shown that these materials had mainly eliminated the widely differing effects of crops, the fertilizer added since then has been acidic and the amount of phosphorus has been reduced.

The single crop was carrots in 1923 (Thirty-sixth Annual Report), and the yield was from 692 to 999 bushels following the different crops. The H-ion concentration had then been increased to about pH 6, and the active alumina was about 400 parts per million. Such conditions are not too acid for carrots. They would be more liable to be undesirable because of some factor such as a deficiency of manganese which has frequently exerted an effect where the soil has been entirely neutralized by liming (Thirty-eighth Annual Report). In the autumn of 1924, the soil showed an average pH of about 5.6 and a calcium oxid absorption of about 1,300 pounds per acre.

Timothy is now becoming established as the single crop for its main response in 1927 under conditions which may be somewhat critical for this grass, which has a rather low resistance to acid-soil conditions.

MASON JARS AS MINIATURE SILOS[1]

R. J. GARBER AND T. E. ODLAND[2]

In connection with certain varietal and cultural investigations with maize conducted at the West Virginia Experiment Station, it was found desirable to make determinations of yields of silage. This could not be done easily unless a method was found whereby it would not be necessary to handle a relatively large sample of the crop from each group of plats similarly treated or planted to the same variety. The silage was to be used for making a chemical analysis only, and therefore, but a small sample was required. The problem then was to work out a method which would be used to convert a small sample of corn forage into silage comparable to that usually formed in an ordinary silo.

LITERATURE REVIEW

Small wooden or metal silos as well as glass jars have been used by a number of investigators in studying silage formation. Where sealed jars have been used, provision has usually been made for allowing excess gasses to escape. The use of small silos and jars for making silage in the laboratory has usually been reported as giving very satisfactory results.

Babcock and Russell (1)[3] used galvanized iron receptacles containing about 200 pounds of corn forage each in studies on silage formation. These receptacles were filled and sealed, but provision was made for the escape of gas. Characteristic silage was obtained by this method.

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[1] Approved by the Director for publication as Scientific Paper No. 33 from West Virginia Agricultural Experiment Station, Morgantown, W. Va. Received for publication December 27, 1926.

[2] Agronomist and Associate Agronomist, respectively.

[3] Reference by number is to "Literature Cited," p. 263.

Eckles, Oshel, and Magruder (2), in certain parts of their silage investigations, used tin cans holding approximately 10 gallons each. The lids were put on with heavy pressure, wired down, and sealed. The authors state that the silage made in this way did not spoil and was similar to silage from a large silo.

Lamb (4), in studies of the relative influence of micro-organisms and plant enzymes on corn silage, used wide-mouth glass jars closed with rubber stoppers. Each jar was provided with an outlet tube for excess gasses. The tube was closed with a pinchcock. The silage, made in this manner, the author states, was similar to that from the farm silo both in appearance and in chemical composition.

Peterson, Hastings, and Fred (5) used milk bottles closed with a one-hole rubber stopper for making corn silage. A bent glass tube sealed with mercury was passed through the stopper in order to allow gasses to escape. A strong evolution of gas was noted. The silage obtained had the same odor and taste as normal silage.

Hunter and Bushnell (3), in bacteriological and chemical studies of different kinds of silage, used quart milk bottles which were sealed air-tight by means of rubber stoppers wired in place. The silage thus obtained, the authors state, resembled silage made by the usual method in respect to bacteriological and chemical analyses together with odor.

METHOD

In 1923, at the time the silos on the dairy farm were being filled, a composite sample of corn was run through a small hand cutter (pieces cut about one-fourth of an inch in length). This composite sample was thoroughly mixed and then small samples were drawn from it and placed either in Mason jars or in muslin bags. Fifteen 2-quart Mason jars were filled by firmly tamping the cut corn into them and at the same time adding just a little water. After the jars were filled, the screw caps were placed in position but no rubber rings were used, hence the jars were not sealed. The jars were kept in a moderately cool place. The remainder of the composite sample was distributed in 30 muslin bags, placing a somewhat larger quantity of the material in each bag than was tamped into a jar. One-half of the partly filled bags were hung in a drying room and the other half were buried in the silo. Later on (about mid-winter), when the samples which had been buried in the silo were uncovered, all samples, including those in jars and the air-dry samples, were analyzed[4] for crude protein, fat, fiber, nitrogen-free extract, and ash. The analyses are reported on a water-free basis.

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[4] The writers are indebted to T. J. Cochrane of the Agricultural Chemistry Department for the chemical analyses. All analyses were made in duplicate.

In 1925, the method used was similar to that employed in 1923, except in regard to certain important details. In filling the jars in 1925 no water was added and the jars were sealed by using rubber rings. Moreover, in that year 10 samples only were placed under each of the three conditions, i. e., in jars, in the silo, and in the drying room.

RESULTS IN 1923

The average percentage of nutrients contained in the samples at the end of the storage period is shown in Table 1. The material in most of the jars was preserved very well, but in a few jars rather extensive decay had taken place. In all cases the spoiled silage was discarded before making the analysis.

TABLE 1.—*Average percentage of nutrients, determined on water-free basis, in samples of corn forage preserved in different ways in 1923.*

Forage sample	Number of samples	Average percentage of nutrients				
		Protein	Fat	Fiber	Nitrogen-free extract	Ash
Air dry	15	7.42±0.11[a]	1.43±0 03	28.57±0.26	56.33±0.27	6.24±0.06
In jars	15	6.98±0.09	2.35±0.07	29.39±0.35	55.06±0.45	6.21±0.12
In silo	15	7.49±0 16	2.45±0.03	27.48±0.21	56.54±0.29	6.04±0.12

[a] Probable errors calculated by means of Bessel's formula.

The average percentages of protein in the samples stored under the three conditions do not differ significantly, the extreme differences being 0.51 ±0.18%. With respect to fat, the average analysis based on the air-dry samples was somewhat lower, as would be expected, than the average analysis based on the samples in the jars or in the silo. The latter two did not differ significantly. The average analysis for fiber showed considerable difference between the samples in the jars and those in the silo, the difference being 1.91 ±0.41%. The fiber content of the air-dry samples was intermediate between the other two. The relative amount of nitrogen-free extract in the air-dry samples and that in the silo samples was approximately the same, whereas the average of the latter was 1.48 ±0.53% less than that of the samples in the jars. The average percentage of ash was about the same in all three sets of samples.

RESULTS IN 1925

It will be recalled that in 1925 no water was added as the jars were being filled and also that the jars were sealed. Under these conditions the silage formed was perfectly preserved and did not show

TABLE 2.—*Percentage of nutrients, determined on water-free basis, in samples of corn forage preserved in different ways in 1925.*

Protein in samples			Fat in samples			Fiber in samples			Nitrogen-free extract in samples			Ash in samples		
Air dry	In jars	In silo	Air dry	In jars	In silo	Air dry	In jars	In silo	Air dry	In jars	In silo	Air dry	In jars	In silo
5.33	5.17	5.85	2.02	1.93	2.23	27.23	26.37	24.96	59.96	61.24	61.33	5.46	5.28	5.62
6.00	5.34	5.77	2.32	2.19	2.01	24.68	24.02	23.07	62.32	62.99	64.50	4.68	5.46	4.65
5.18	5.51	5.75	1.78	2.42	3.07	27.80	23.14	19.87	59.82	63.70	66.39	5.42	5.22	4.92
5.54	5.82	6.00	2.04	2.41	2.19	24.81	22.52	23.29	62.98	63.92	63.57	4.64	5.32	4.94
5.64	5.60	5.69	2.05	2.35	2.75	26.17	23.63	23.10	60.88	63.60	64.07	5.25	4.82	4.39
5.08	5.36	6.42	1.88	2.49	2.27	27.95	24.24	24.04	59.88	62.96	62.28	5.21	4.95	4.99
4.41	5.43	6.65	1.87	2.30	2.15	27.19	23.31	23.77	60.64	63.58	62.21	5.89	5.37	5.21
5.58	5.85	4.88	1.85	2.38	2.65	27.64	23.64	24.31	59.28	62.75	62.70	5.66	5.38	5.45
4.89	5.44	6.42	1.87	2.18	4.06	26.14	24.87	26.06	61.78	61.47	58.16	5.31	6.04	5.29
5.57	5.81	5.95	2.06	2.19	2.17	25.52	23.65	25.52	61.51	63.57	60.42	5.34	4.78	5.94
5.32± 0.10[a]	5.53± 0.05	5.94± 0.11	1.97± 0.03	2.28± 0.03	2.55± 0.13	26.51± 0.26	23.94± 0.23	23.80± 0.36	60.90± 0.26	62.98± 0.20	62.56± 0.49	5.29± 0.08	5.26± 0.08	5.14± 0.10

[a] Probable errors calculated by means of Bessel's formula.

evidences of mold and decay as in the previous year when slight additions of water were made to the green material and the jars were not sealed.

The data collected in 1925 are shown in Table 2. The analysis of each sample stored in one of three ways is shown. An examination of the means, together with their probable errors listed at the bottom of the table, shows that there is a very close correspondence between the average analysis with respect to fat, fiber, nitrogen-free extract, and ash of the samples in the jars and the samples in the silo. In crude protein the average difference between the samples stored under the two conditions was 0.41 ±0.12%, a small difference but somewhat more than three times its probable error.

The difference between the average percentage of crude protein in the air-dry and in the jar samples was not significant. With respect to the average ash analysis, all three sets of samples were approximately the same. The air-dry samples were somewhat lower in fat and nitrogen-free extract and somewhat higher in fiber than either the samples in the jars or in the silo. It is evident from Table 2 that, in general, the analyses based on the silage formed in the Mason jars and that formed in the silo correspond very closely.

SUMMARY

Mason jars (2-quart size) were found very satisfactory containers for producing corn silage. Corn forage was cut into pieces about one-fourth of an inch in length and firmly tamped into jars, after which the jars were sealed and placed in a moderately cool storage room. The material so preserved could not be distinguished from silage preserved in an ordinary silo, except the former had a somewhat lighter color. The chemical analyses of the silage produced in the two ways were approximately the same.

Corn forage preserved for a few months as air-dry material contained a considerable lower percentage of fat than when preserved for the same length of time as silage.

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AGRONOMIC AFFAIRS

JOURNALS WANTED

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NEWS ITEMS

R. G. WIGGANS, Assistant Professor of Plant Breeding of Cornell University, sailed in February for Nanking, China, to continue the program of crop improvement undertaken cooperatively by the International Eudcation Board, Cornell University, and Nanking University. This work was begun in 1925 by H. H. Love, and continued last year by Clyde H. Myers. Dr. Wiggans' plant-breeding experiments at Cornell University will be continued during his absence by George F. Sprague, a graduate student.

THOMAS BREGGER, formerly of the Porto Rico Station, and for the past three years in charge of corn breeding for the Department of Agriculture of Argentina, returned to the United States last August and is engaged in graduate study for his doctorate degree at Cornell University.

BURTON B. BAYLES, a graduate of the Kansas Agricultural College in 1922, and since 1923 serving as Junior Agronomist in cooperative cereal breeding at the Sherman County Branch Station, Moro, Oregon, for the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, was transferred in February to take charge of the cooperative cereal investigations at the Judith Basin Substation, Moccasin, Montana, succeeding R. W. May.

ON DECEMBER 6, 1926, Carleton R. Ball, Senior Agronomist in charge of the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, addressed a joint meeting of the Society of Sigma Xi and the Honor Society of Phi Kappa Phi at Iowa State College on the subject "The Scientist and Society." On December 8, this address was repeated before the Honor Agricultural Society, Gamma Sigma Delta, and the faculty of the College of Agriculture of the University of Minnesota at University Farm, St. Paul.

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A THRESHER FOR THE PLANT BREEDER AND THE CEREAL CHEMIST[1]

W. O. WHITCOMB[2]

The problem of threshing small quantities of grain easily and quickly without danger of mixing is one of the tasks of the plant breeder and the cereal chemist. The lack of a simple machine that will do this work has impeded the progress of both groups of scientists. There are many highly trained men who are spending much time in threshing by hand a large number of individual plants or other small lots of grain each year.

The recent development of interest in the protein test as a basis for buying wheat makes another need for a thresher of this kind. Judging from the experience of the past two years the testing of wheat before harvesting and threshing so that the producer will know the protein content of his crop when it is threshed will become rather general. A thresher of this kind at the testing laboratory or some other convenient place will prove a valuable asset.

In the summer of 1924, the writer planned and built the thresher described in this paper. The interest manifested in this thresher by visitors during the past two seasons prompted the writing of this paper. It was with a knowledge of the construction of the small thresher used by the Plant Breeding Department of Cornell University in 1913 that this task was undertaken. However, this thresher differs from the Cornell thresher in that it is more readily adapted to different kinds of work. The Cornell thresher was constructed for the purpose of threshing a few heads of grain or at most a single plant at a time, while the Montana machine will thresh a dozen or more plants as readily as it will a single head. The needs of both the plant breeder and the cereal chemist were kept in mind in the planning of this thresher.

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[1] Contribution from the Grain Inspection Laboratory, Montana Agricultural Experiment Station, Bozeman, Mont. Published with the approval of the Director. Received for publication January 4, 1926.

[2] Superintendent.

The California thresher for single heads of grain was designed by Hoffman[3] in 1925. This machine differs from the Montana thresher in that it has no toothed concave and the cylinder is mounted directly on the motor shaft. It is also necessary to remove the heads from the straw before depositing in the hopper and it has a more limited capacity than the Montana thresher.

CONSTRUCTION OF MONTANA THRESHER

Simplicity and durability were kept in mind in planning this thresher. It is so planned that any woodworker with ordinary tools can construct it in about two days' time. The cost of the material need not exceed $8 to $10. A complete list of the material follows

1 clear pine ⅞″ x 12″ x 14′
1 clear pine ½″ x 8″ x 5′
2 pine 2″ x 2″ x 20″
1 seasoned oak 2″ x 6″ x 36″
2 round iron bars $\frac{3}{16}$″ x 12′
4 bolts with slotted heads ¼″ x 5″
12 stove bolts ¼″ x 2½″
4 flat-headed wood screws 2″ long.
24 flat-headed wood screws 1″ long.
6 dozen round-headed wood screws 2½″ long
4 angle irons 4″ x 6″
1 sheet metal about 21″ x 24″.
2 heavy iron washers with holes about 1½″ diameter.
1 steel shaft 1″ diameter by 20″ long.

CYLINDER

The construction of the cylinder is shown in Fig. 1. An end view is shown (1) of the blocks of oak which have been fastened together with screws and bolts. The steel shaft is clamped in the center of this block by means of the bolts, after which it is placed in a lathe and turned out into a cylinder 6 inches in diameter and 8 inches long. Lines are drawn around the cylinder ¾ of an inch apart. Ten holes ¾ inch deep are bored with a $\frac{3}{16}$ inch twist drill on each of these lines at intervals around the cylinder. The teeth which have been cut in lengths of 1½ inches from the iron bar are driven into these holes as shown in 2 of Fig. 1. This makes a very solid cylinder with a diameter of 7½ inches from the tip to tip of teeth.

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[3] HOFFMAN, A. H. A thresher for single heads of grain. Jour. Agr. Eng., 6: 297, 1925.

BEARINGS

The ends of the cylinder at the shaft are fitted with heavy iron washers which are screwed to the blocks and serve to prevent end motion of the cylinder. These washers form a bearing with the sheet metal which lines the housing at this place.

The bearings in which the cylinder shaft runs are made of seasoned oak blocks. These blocks are each 1 inch thick, 2 inches wide, and 6 inches long. The block for each bearing is split and fitted with bolts so it can be adjusted readily.

CONCAVE

The construction of the concave is shown in 3 of Fig. 1. Two blocks of oak, each of which is 2″ x 3″ x 7½″, are fastened as indi-

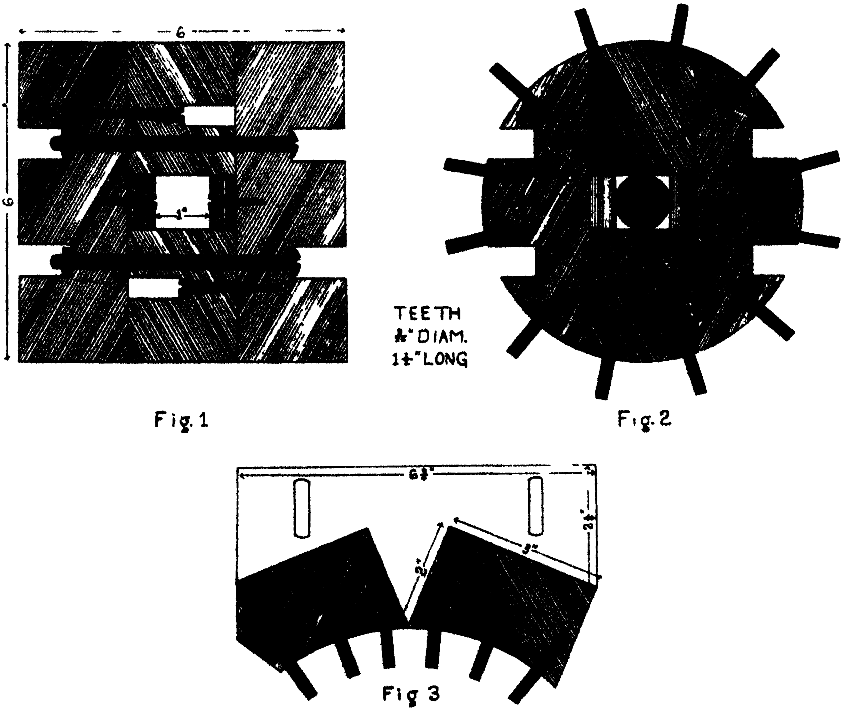

Fig. 1

Fig. 2

Fig 3

FIG. 1.—Cross-sectional view of cylinder and concave.

1. Shows the three blocks of oak held in place by means of screws and bolts
2. Shows the shaft in place and the blocks turned into a cylinder and the teeth in place.
3. Shows the concave constructed of two blocks of oak held in place by means of the sheet metal on the ends and the teeth set in place.

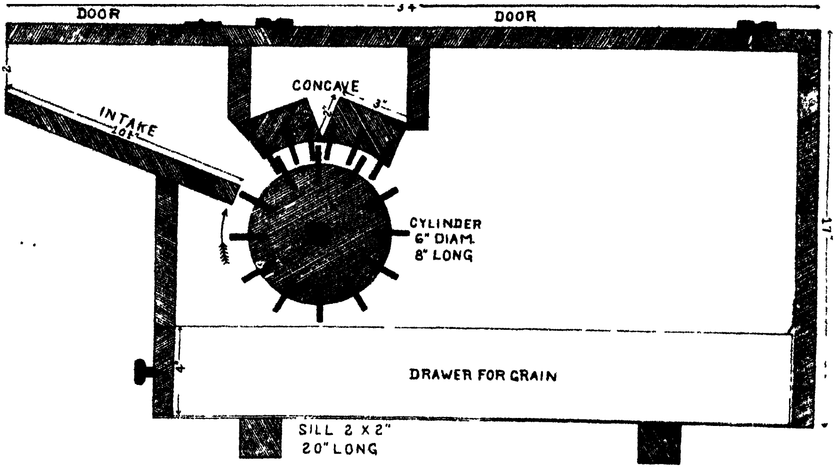

FIG. 2.—Sectional view of housing with cylinder and concave in place. The construction is simple so no grain can lodge and cause mixing.

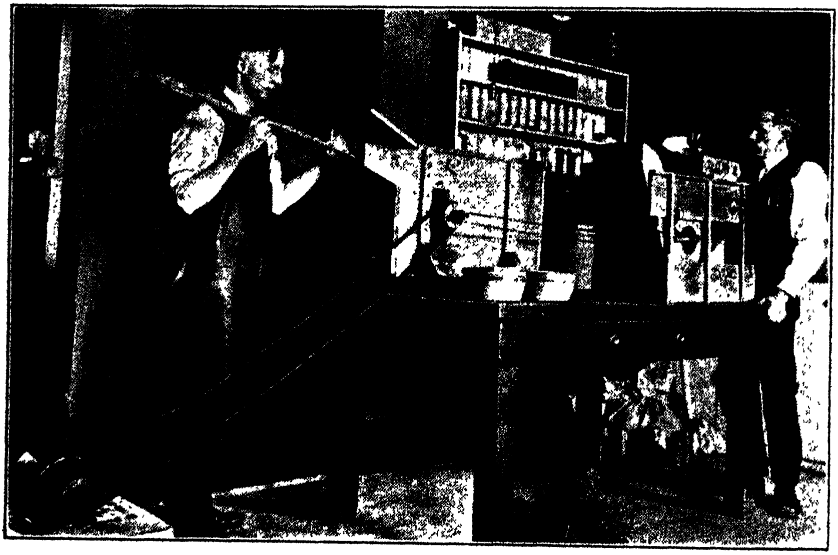

FIG. 3.—The thresher in operation. The small fanning mill is run from the cylinder shaft. A ¼ horse power motor is ample power. Two men can average four to six plants a minute.

cated by securely fastening a strip of sheet metal at each end by means of screws. The lower surface of the blocks is then made concave and lines drawn ¾ inch apart and teeth set as in the cylinder. The number of teeth provided for is 72, but this may be reduced if desired. The slotted holes in the sheet metal at each end provide for a means of lowering or raising the concaves to suit the needs of the operator. The clearance between the cylinder and concave teeth is $\frac{3}{16}$ of an inch which is the same as the diameter of the teeth. The concave is adjusted endwise in relation to the cylinder by a screw in each side of the housing which is used to push the concave either way as desired.

HOUSING

The housing with the cylinder and concave in place is shown in Fig. 2. It is constructed of pine and fastened together with large screws. The sills which support the housing are attached with angle irons. The doors are provided on top. One of these is to be raised to permit the entrance of the grain, the other when removed makes the entire inside of the machine accessible. The drawer for grain can be constructed of either wood or sheet metal; the latter has been found more satisfactory. Metal guides are placed on the sides and ends just above the drawer to prevent the loss of any grain. The machine is so constructed that it does not permit the lodging of any grain and thus mixing is prevented.

OPERATION OF THE MONTANA THRESHER

This thresher was used during 1924 and 1925 and gave excellent satisfaction. The grain threshed from single plants can be readily cleaned by letting it fall before the draft of an electric fan or similar device, but a small clipper fanning mill which is run by a belt from the cylinder shaft has been found to be more satisfactory. The small fanning mill is more necessary when threshing larger quantities than single plants. The power required to operate both the thresher and the fanning mill need not be more than a ¼ horse power electric motor with a speed of 1,150 revolutions per minute. The best speed for the cylinder was found to be 1,200 to 1,400 revolutions per minute.

The removal of the grain drawer for each plant or other unit insures against mixing the grain. In feeding the grain into the cylinder the door is raised to permit the placing of the plant or bundle in the chute and then it is lowered to prevent any kernels from being thrown out. The straw is held by the hand until the heads have been removed and then it is discarded. This allows only the chaff and a small amount of straw to be deposited with the grain in the drawer.

Two men working with the thresher and fanning mill combined, as shown in Fig. 3, can average from four to six plants per minute.

The writer will be pleased to answer any inquiries relative to the construction or operation of this thresher.

EFFECT OF RATE AND METHOD OF APPLICATION OF FERTILIZER ON THE GERMINATION OF WHITE BEANS[1]

C. E. Millar and J. F. Mitchell[2]

INTRODUCTION

The annual summary of the Michigan Crop Report for 1924 credits Michigan with the production of 75% of the white beans grown in the United States. Nevertheless, it is an unfortunate fact that little definite information is available regarding the fertilization of this crop and in certain localities there is still some prejudice against the use of commercial fertilizers in bean growing.

The results of several years of field experimentation by the Soils Department have given valuable information regarding proper fertilizer analyses for beans, but they have also given rise to a number of very pertinent questions regarding fertilizer practice. The work here reported was undertaken in an effort to answer some of these questions.

HISTORICAL

The writers have found very few reports of experiments dealing with the influence of fertilizers on the germination and growth of white beans. In the references found failure to give rate and method of application of the fertilizer and lack of sufficient information regarding the nature of the soil used have rendered the data of little assistance. A number of excellent papers bearing indirectly on the subject have been of assistance and reference to them is made at various points in the body of this report.

EXPERIMENTAL

A rather heavy Brookston loam and a heavy phase of the Hillsdale sandy loam, which are quite representative of the soils on which a large acreage of beans are grown, were selected for the work.

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[1] Contribution from the Division of Soils, Michigan State College Experiment Station, East Lansing, Mich. Received for publication January 4, 1927.

[2] Professor in Soils and graduate student, respectively.

In view of the rapidly growing interest in the use of concentrated fertilizers and in consideration of the fact that field experiments have shown phosphoric acid to be the plant food element most generally needed by the soils in the bean-growing sections of Michigan, Anaconda or treble superphosphate was given major consideration. Since 16% acid phosphate has been something of a standard fertilizer and also affords a comparison for the more concentrated phosphate, it was included in the tests. As the work progressed it was found desirable to utilize mono-calcium-phosphate of C. P. grade to some extent. A complete fertilizer with a 3-12-4 composition, representing a good grade of commercial goods, was also included.

At the present time nearly all of the drills used by farmers for sowing beans place the fertilizer in direct contact with the seed. In consequence this method was given major consideration. Realizing, however, that this practice is open to considerable criticism, other methods of application, such as placement above the seed and broadcasting, were employed.

EFFECT OF FERTILIZERS PLACED IN DIRECT CONTACT WITH SEED

In this experiment wooden trays about 4 inches deep were used as containers In calculating the amount of fertilizer, it was assumed that the rows of beans were to be 24 inches apart This agrees with field practice in certain portions of the bean district, while in other sections the standard distance is 28 inches It was assumed rather arbitrarily that the fertilizer would spread in the row to a width of 1½ inches In actual practice it is probable that the width covered is less rather than greater than this figure

In planting, a layer of soil was placed in the tray and the seed laid in rows on the surface The fertilizer was then sprinkled over the seed in a strip 1½ inches wide Another layer of soil was used to cover the seed and fertilizer.

The results from the use of Anaconda and C. P. mono-calcium phosphate are shown in Table 1.

In the trial with Anaconda on sandy loam so few of the plants emerged from the soil that the percentage of seeds and sprouts showing injury from the fertilizer is reported in place of the percentage of plants coming through the soil, as is done in the other experiments.

It is rather surprising to note that so small an amount of Anaconda as 20 pounds per acre applied in direct contact with the beans caused some decrease in germination, while a 30-pound application cut the germination to 45%.

TABLE 1.—*Effect of Anaconda and mono-calcium phosphate on the germination and early growth of beans when applied in direct contact with the seed.*

Fertilizer, pounds per acre	Hillsdale sandy loam				Brookston loam	
	Anaconda		Mono-calcium phosphate		Anaconda	
	Germination	Injury	Germination	Plants coming through soil	Germination	Plants coming through soil
	%	%	%	%	%	%
0	95	0	100	100	95	95
10	95	60	100	100	—	—
20	90	95	100	100	95	85
30	45	100	100	100	90	70
40	20	100	95	95	70	15
50	15	100	95	95	85	20
60	—	—	95	95	85	30
70	—	—	—		70	5
100	—	—	85	85	—	—
120	—	—	95	85		—
150	—	—	75	75	—	—

With an application of 10 pounds per acre germination was unimpared, but 60% of the plants showed some injury. This was slight, however, and it is reasonable to suppose that the damage would have been overcome if the plants had been allowed to grow. With an application of 20 pounds, 65% of the seeds developed fairly good sized sprouts, but they were all damaged quite severely and 25% developed only very small sprouts. An application of 30 pounds per acre damaged very seriously practically every sprout from the 45% of the seed that germinated. Higher applications not only reduced germination to very low percentages, but inhibited the growth of sprouts which emerged from the seed.

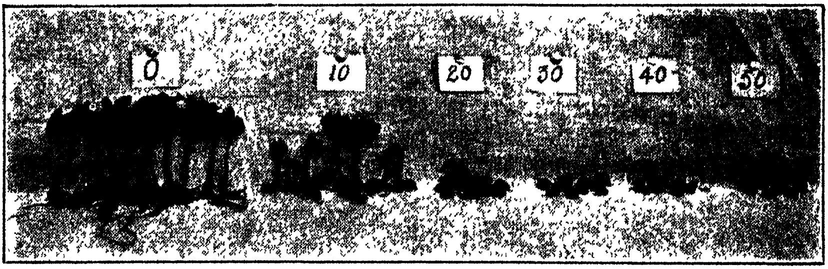

FIG. 1.—Effect of Anaconda phosphate on the germination and early growth of white beans when applied in direct contact with the seed in sandy loam soil. Figures refer to pounds of fertilizer per acre.

The effect of Anaconda on germination and the extent of the damage to the sprouts in sandy loam is well shown in Fig. 1.

When the heavy loam was used an application of 20 pounds of Anaconda did not cause so much damage as did a 10-pound application on the sandy loam. This is in accord with the results of Harris (4)[3] who found that only about one-half as much fertilizer was required to inhibit growth on a sand as on a loam.

It required 40 pounds or more of Anaconda to reduce germination materially in this soil, but it is noteworthy that 20 pounds was sufficient to turn the roots brown and prevent about 10% of the plants from coming through the ground. Thirty pounds prevented the development of root hairs and the roots themselves were very much restricted in development and presented an unhealthy appearance. An application of 40 pounds not only inhibited practically all root development, but destroyed most of the leaves. The detrimental effect of higher applications, as well as of the small ones, is well shown in Fig. 2.

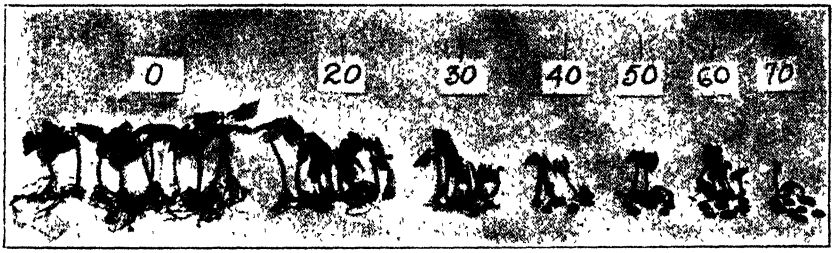

FIG. 2.—Effect of Anaconda phosphate on the germination and early growth of white beans when applied in direct contact with the seed in heavy loam soil. Figures refer to pounds of fertilizer per acre.

In consideration of the severe damage caused by light applications of Anaconda, particularly on the sandy loam, it is interesting to note the comparative harmlessness of chemically pure mono-calcium phosphate under similar conditions. In all of the treatments the plants coming through the soil had broader leaves, a more healthy appearance, and better root development than did any of the plants fertilized with Anaconda.

The root development of all plants receiving applications below 100 pounds was as good and in many cases better than that of the unfertilized plants. The growth of plants in all cultures receiving less than 60 pounds showed an appreciable stimulation. Applications of over 60 pounds produced an increasing tendency to turn some of the seeds brown and the plants showed somewhat less vigor than those receiving no fertilizer. In no case, however, even with the 150-pound treatment, did the plants show such serious damage as was produced by 20 pounds of Anaconda.

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[3] Reference by number is to "Literature Cited," p. 279.

These data plainly indicate a toxicity in Anaconda not accounted for by the mono-calcium phosphate content. Experiments are being conducted to determine the cause of this toxicity.

Fig. 3 shows the influence of mono-calcium phosphate on germination and growth of the leaves.

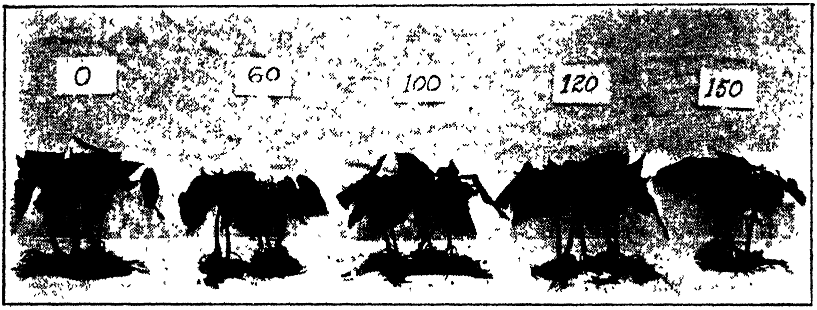

FIG. 3.- Effect of C. P. mono-calcium phosphate on the germination and early growth of white beans when applied in direct contact with the seed in sandy loam soil. Figures refer to pounds of fertilizer per acre.

In Table 2 are given the results of the experiments in which 16% acid phosphate and a commercial 3-12-4 mixture were applied in direct contact with the seed.

Applications of 16% acid phosphate did not decrease germination on the sandy loam, even when as much as 350 pounds per acre were applied. The smaller additions of 50 pounds and less stimulated the plants in the earlier stages of growth. This handicap, however, was later overcome by the plants receiving applications of 200 pounds and less. Amounts of acid phosphate in excess of 200 pounds tended to retard growth, and in the heavier applications some damage to the leaves was apparent.

On the Brookston loam germination was not impaired by acid phosphate, but there was more damage to the plants from applications of 300 pounds and more than was observed in the case of sandy loam with similar applications. The writers have no explanation to offer for this.

The commercial 3-12-4 fertilizer did not inhibit germination to an appreciable extent in any of the amounts used. Plant growth,

TABLE 2.—*Effect of 16% acid phosphate and of commercial 3-12-4 fertilizer on the germination and early growth of beans when applied in direct contact with the seed.*

Fertilizer, pounds per acre	Hillsdale sandy loam				Brookston loam			
	16% acid phosphate		Commercial 3-12-4		16% acid phosphate		Commercial 3-12-4	
	Germination	Plants coming through soil	Germination	Plants coming through soil	Germination	Plants coming through soil	Germination	Plants coming through soil
	%	%	%	%	%	%	%	%
0	95	95	95	95	100	100	100	100
100	100	100	100	100	—	—	—	—
120	90	85	85	85				—
160	95	85	90	80	—	—	—	—
200	90	85	95	75	—		—	—
240	90	90	100	65	100	95	—	—
260	85	85	95	50	90	85	100	100
280	90	85	90	40		—	—	—
300	90	90	85	50	95	70	100	95
325	100	70	90	40	90	45	100	85
350	90	80	90	50	100	55	100	85

however, was greatly influenced, particularly in the sandy loam. Applications of 100 pounds and less caused a stimulation of growth as compared with the unfertilized plants. Some indication of leaf injury was noted with the 120-pound application and damage to some of the seeds was noted with the 160-pound application. Seed and plant damage increased with the heavier applications, becoming quite serious with amounts of 200 pounds and over as shown by the percentage of plants coming through the soil.

In trials with the heavy loam germination was perfect in all cases, although with the heavier applications some of the seeds molded after germinating. Some of the plants were not so thrifty as were those receiving no fertilizer or the lighter applications, and in some cases there was leaf injury. The damage as a whole was much less than in the trials with the sandy loam, which is contrary to the results for 16% acid phosphate but agrees with the findings of Coe (2, 3), Hicks (5), Allison (1), Harris (4), and others.

EFFECT OF FERTILIZERS APPLIED ABOVE SEED

Tumblers were used for containers in this experiment and the fertilizer was placed about one-half inch above the seed. The results of the trials on sandy loam, which was the only soil used, are shown in Table 3.

As might be expected much larger quantities of Anaconda were required to decrease germination when applied above the seed than when in direct contact with the beans. Very serious damage to the shoots, however, resulted from Anaconda placed in this position.

TABLE 3.– *Effect of fertilizers applied above the seed on the germination and early growth of beans in sandy loam soil.*

Fertilizer, pounds per acre	Anaconda		16% acid phosphate		Commercial 3-12-4	
	Germination	Plants coming through soil	Germination	Plants coming through soil	Germination	Plants coming through soil
	%	%	%	%	%	%
0	95	95	90	90	90	70
25	90	70		-	--	—
50	90	40	—	-	--	—
75	90	10	–	--	—	—
100	100	0	80	80	90	80
150	50	0	100	80	100	90
200	50	0	90	90	80	50
250			90	80	100	90
300		–	100	90	100	40
350			90	80	90	80
400	--	-	100	100	100	40

An application of 25 pounds prevented 30% of the plants from coming through the soil, while 50 pounds per acre damaged 60% of the plants to such an extent that they did not emerge. The root systems in both cases showed no restriction or damage. With an application of 75 pounds some injury to the root system was observed as well as very severe damage to the sprouts The damage to both roots and tops increased with increasing amounts of fertilizer, until with a 200-pound application there was practically no development of either.

Although the injury from Anaconda above the seed was not quite so serious as when in direct contact, it is evident that this method of application is not practical since vertical diffusion is quite rapid, especially after a rain as pointed out by Coe (2) and Allison (1). With this method of application the damage to young sprouts was quite severe, which, as pointed out by Hicks (5), is doubtless one of the main stages of fertilizer injury.

Fig. 4 shows the effects of Anaconda on the germination and early growth of the beans when applied above the seed in sandy loam soil.

The 16% acid phosphate applied above the seed caused no damage even when as much as 400 pounds per acre were applied. Applications up to and including 300 pounds stimulated growth sufficiently so that the plants were noticeably larger than those receiving no fertilizer. Applications of 350 and 400 pounds, however, caused some

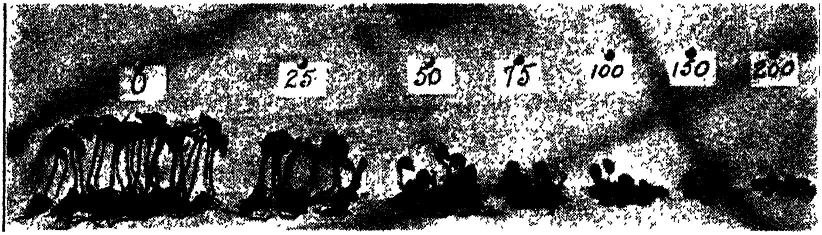

FIG. 4.—Effect of Anaconda phosphate on the germination and early growth of white beans when applied above the seed in sandy loam soil. Figures refer to pounds of fertilizer per acre.

decline in size and the plants did not appear as healthy as those receiving smaller amounts of phosphate.

Commercial 3-12-4 fertilizer in amounts up to and including 200 pounds per acre produced plants which were more vigorous than those receiving no fertilizer. While 50% of the plants failed to come through the soil in the case of the 200-pound treatment, those which did were quite vigorous and showed no ill effects from the fertilizer. With 250-pound applications the plants exhibited less vigor, and as the applications increased very severe damage resulted as is shown in Fig. 5.

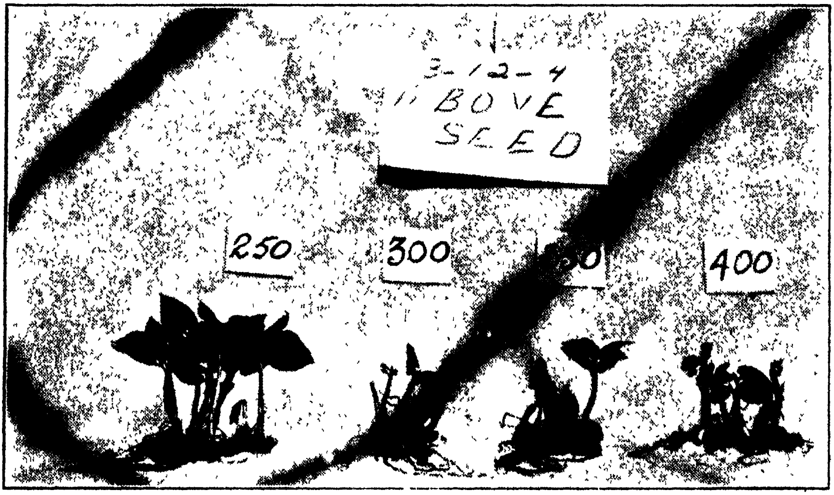

FIG. 5.—Effect of commercial 3-12-4 fertilizer on the germination and early growth of white beans when applied above the seed in sandy loam soil. Figures refer to pounds of fertilizer per acre.

EFFECT OF ANACONDA APPLIED BROADCAST

Inasmuch as the preceding experiments showed that considerable amounts of the fertilizers used, other than Anaconda, were required to decrease germination and damage the sprouts when in direct contact with the seed, it was decided to confine the broadcast trials to Anaconda.

Tumblers were used as containers in this experiment and into each was placed 100 grams of soil. The fertilizer was thoroughly mixed with the soil to a depth of 2 inches.

Germination counts were made seven days after planting so none of the plants had an opportunity to emerge from the soil. Applications up to and including 350 pounds caused no decrease in germination, but when this application was doubled germination was entirely inhibited. Since it is improbable that field applications would exceed 350 pounds per acre of such a concentrated fertilizer, trials were not made to determine the exact point at which decreased germination results. Whether or not the sprouts would have been damaged by applications of 350 pounds or less was not determined. It is realized that the thoroughness with which the fertilizer was mixed with the soil could scarcely be duplicated under field conditions.

CONCLUSIONS

When applied in direct contact with the seed, extremely light applications of Anaconda phosphate greatly decreased the germination of white beans in sandy loam soil. In a heavy loam somewhat larger amounts were required. Severe injury to the sprouts was caused by smaller applications of fertilizer than were required to decrease germination. This form of damage was much more serious than the influence on germination.

Chemically pure mono-calcium phosphate was much less toxic to the sprouts and was not nearly so detrimental to germination as was the Anaconda. This leads to the conclusion that some impurity in the Anaconda is primarily responsible for its extreme toxicity. An effort is being made to determine the nature of this impurity.

Applied above the seed over 100 pounds of Anaconda were required to decrease germination in a sandy loam soil under the conditions of the experiment. It is noteworthy, however, that 25 pounds caused serious injury to the sprouts.

Since serious damage was caused by smaller amounts of Anaconda than the ordinary distributing machinery can be relied on to apply accurately, it is evidently not advisable to apply this fertilizer in the row or above the seed when planting beans.

When applied broadcast and thoroughly mixed with the surface 2 inches of soil, 350 pounds of Anaconda had no retarding influence on germination of white beans.

Applications of 16% acid phosphate up to and including 350 pounds per acre in direct contact with the seed did not decrease germination. In amounts of 50 pounds and less in direct contact with the seed in sandy loam, acid phosphate stimulated the early growth of the bean plants. Applications of 200 pounds and more resulted in retardation of growth due doubtless to the high osmotic pressure of the soil solution. With the heavier applications some leaf injury was noted.

Applications of as much as 400 pounds of acid phosphate placed above the seed caused no decrease in germination or injury to the plants in sandy loam.

Complete commercial fertilizer with a 3-12-4 composition proved more toxic than 16% acid phosphate when applied in direct contact with and above the seed. This is probably due to the high solubility of the ammonium and potassium salts present.

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EFFECT OF CROPPING ON THE NITROGEN AND ORGANIC CARBON OF IRRIGATED SOILS[1]

HOWARD V. JORDAN[2]

The effect of cropping on the nitrogen and organic carbon of soils has been made the object of considerable study. Such studies have been made both in humid regions and in semi-arid regions where farming is done by so-called "dry-farming" methods. The results of these investigations are so well known as to require only brief mention here.

STUDIES IN NON-IRRIGATED REGIONS

As fairly typical of such studies in humid climates the results of Wiancko, Conner, and Jones (12, p. 4)[3] in Indiana, of Whitson, Stoddart, and McLeod (10, 11) in Wisconsin, and of Snyder (6) in Minnesota may be cited. All have found striking losses of nitrogen as a result of cropping; and in Indiana, where organic carbon was measured, corresponding losses were noted.

Whitson, Stoddart, and McLeod (11) observed that the greatest losses of nitrogen occurred from those soils which had a rather high initial content.

Swanson and Latshaw (8) found cropped soils in both the humid and sub-humid portions of Kansas to be lower in nitrogen and organic carbon than adjacent virgin sod. This was true irrespective of whether alfalfa had been grown. In the semi-arid portion of that state where alfalfa had grown an increase in nitrogen was noted, but there was a decrease in organic carbon. Cropped soils of the semi-arid region which had not grown alfalfa were lower in both nitrogen and organic carbon than adjacent virgin sod.

Alway (1) compared in composition a number of long-cultivated fields in the loess area of Nebraska with the adjacent prairie A decline in nitrogen and organic carbon was noted in all cases.

For typical dry-farming areas similar data are available. Stewart (7) found fields cropped to grain in the Cache Valley, Utah, to contain more nitrogen and humus than adjacent virgin soils. His results are not in agreement with those of other workers in dry-farming areas, however.

Thatcher (9) has reported losses of both nitrogen and organic carbon from the dry-farmed soils of Washington as a result of cropping, and a similar condition was found in the soils of the lower Columbia River basin by Jones and Yates (3). Shutt (4) found that after 22 years of cultivation a prairie soil of western Canada had lost 2,190 pounds of nitrogen from the surface 8 inches of an acre.

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[1] Contribution from the Department of Agronomy, New Mexico Agricultural Experiment Station, State College, N. M. Received for publication January 12, 1927.

[2] Assistant Agronomist.

[3] Reference by number is to "Literature Cited," p. 284.

IRRIGATED SOILS

Less is known of the effect of cropping on the nitrogen and organic carbon of irrigated soils, and these soils present an interesting and peculiar problem. Confined to arid and semi-arid regions, the sparse vegetative cover which they originally supported has given little opportunity for the accumulation of organic matter. They are correspondingly low in nitrogen. The effect of bringing these soils under irrigation may be equivalent to that of transporting them to a humid environment. Yields are large, in striking contrast to the scattered vegetation which originally occupied the land. Cropping, because of the residues left in the soil, may increase the organic carbon rather than the reverse; and this may be true of nitrogen also. Such an increase in organic carbon has been noted in the irrigated soils of Washington by Sievers and Holtz (5, p. 7).

The effect of cropping on these soils is one of the problems under investigation at the New Mexico Agricultural Experiment Station. During the course of the work an opportunity for comparing in composition virgin soils with those which had been in alfalfa for varying lengths of time presented itself. The results are discussed in this paper.

The campus of the New Mexico College of Agriculture and Mechanic Arts is located on the foothills bordering the irrigated Mesilla Valley. The soil is classified as the Anthony gravelly sandy loam and is quite uniform over the area occupied by the campus and the immediate vicinity. It consists of a light brown or slightly reddish brown, medium to coarse textured sandy loam, with little change in color or texture to a depth of 6 feet or more. Gravel occurs throughout the soil mass. The native vegetation consisted of scattered chamisa (*Artiplex canescens*), mesquite (*Prosopis glandulosa*), and creosote bush (*Covillea glutinosa*). The average annual rainfall is 8.60 inches.

The campus proper has been brought under irrigation and seeded to alfalfa at different times. At the time of sampling various portions had been growing alfalfa continuously for from two to seven years. Five cuttings are made annually, which have averaged 7 tons per acre per year. All of the alfalfa is removed as hay.

EXPERIMENTAL

Carefully drawn composite samples were secured from the virgin soil bordering the campus on three sides (a different soil type prevails on the west). Other composite samples were secured from portions of the campus where alfalfa had grown for two, three, six, and seven years, respectively. Samples were drawn in three sections, namely, the surface 7 inches, the zone from 7 to 18 inches in depth, and the zone from 18 to 36 inches. Samples were analyzed for nitrogen and organic carbon.

ANALYTICAL METHODS

Moisture was determined by drying samples at 100°C to constant weight, and all determinations were based on the weight of moisture-free soil.

Nitrogen was determined by the modified Kjeldahl method.

Total carbon was determined by combustion with sulfuric acid and potassium bichromate, using the method described by Cameron and Brezeale (2). Inorganic carbon in the form of carbonates was determined in other samples and deducted. Results from this method are known to be low, but it yields accurate comparative data. All samples contained inorganic carbonates.

ANALYTICAL DATA

In Table 1 are shown the percentages of nitrogen and organic carbon in the virgin and cropped soils. These data were secured by analyzing the number of composite samples indicated in the table, and only the average results are recorded. The data are so arranged as to afford a comparison between the virgin soils and (a) those which have been in alfalfa for two and three years and (b) those which have been in alfalfa for six and seven years.

TABLE I. *Nitrogen and organic carbon in virgin and cropped soils.*

Cropping history	Number of samples	Nitrogen %	Organic carbon %
	0 to 7 Inches		
Virgin	3	0.065	0.552
Alfalfa, 2-3 years	2	0.053	0.534
Alfalfa, 6-7 years	2	0.076	0.639
	7 to 18 Inches		
Virgin	3	0.045	0.318
Alfalfa, 2-3 years	2	0.043	0.292
Alfalfa, 6-7 years	2	0.066	0.522
	18 to 36 Inches		
Virgin	3	0.034	0.239
Alfalfa, 2-3 years	2	0.034	0.205
Alfalfa, 6-7 years	2	0.067	0.575

When the virgin soils are compared in composition with those which have been in alfalfa for only two and three years no significant differences are apparent. Both nitrogen and organic carbon are in general somewhat lower in the cropped soils. However, except for nitrogen in the surface 7 inches, the differences are small, and in this surface zone the difference amounts to only 220 pounds of nitrogen per acre. Apparently, no great changes have taken place in this soil as a result of two or three years cropping to alfalfa.

The soils that have been in alfalfa for six and seven years, however, have considerably greater amounts of both nitrogen and organic carbon than adjacent virgin areas. Apparently, growing alfalfa for this longer period of time has resulted in considerable accumulation of both of these constituents. The increases are greater in the subsurface and subsoil sections than in the surface. While the differences are small when expressed on a percentage basis, they assume considerable importance when calculated as pounds of nitrogen and organic matter per acre.

The increase in organic carbon is probably the result of two factors. One is the accumulation of leaves lost in harvesting the alfalfa crop. In its virgin state some organic matter accumulates in the surface of this soil as a result of leaf shedding by native vegetation. The amount of material from this source, however, is increased many fold when the land is irrigated and seeded to alfalfa. A second and probably more important factor is the increased development of roots. Throughout much of the year the moisture content of the surface 3 feet of the virgin soil is too low to encourage much root extension. When brought under irrigation a marked increase in root development in this soil zone occurs.

The increase in nitrogen is probably in large part the result of these same forces accompanied by symbiotic nitrogen fixation. The alfalfa is heavily inoculated. A part may be due to non-symbiotic nitrogen fixation encouraged by the greater supply of organic carbon.

As judged from these data, the effect of cropping irrigated soils of this kind to alfalfa may be quite different from the corresponding effect on soils of non-irrigated regions.

SUMMARY

Studies by others both in humid regions and in "dry-farming" regions have shown that one noticeable effect of cropping has been to decrease the nitrogen and organic carbon of soils.

In the study described herein the nitrogen and organic carbon of a virgin arid soil was compared with that in similar adjacent soils that had been irrigated and growing alfalfa for two, three, six, and seven years, respectively. No significant differences between the virgin soils and those in alfalfa for two and three years were noted. Where alfalfa had grown for the longer period considerably greater amounts of both nitrogen and organic carbon were found.

The increase in organic carbon is attributed in part to the accumulation of leaves lost in harvesting the alfalfa and in part to greater root development in the irrigated soil. The increase in nitrogen is attributed largely to the same forces accompanied by symbiotic nitrogen fixation.

The conclusion is drawn that where a good rotation including alfalfa is practiced on irrigated soils of this kind, the problems incident to maintaining nitrogen and organic matter are not so great as in non-irrigated regions.

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CHEMICAL DETERMINATIONS TO BE MADE IN THE COURSE OF A SOIL SURVEY[1]

P. L. GILE[2]

The question of what chemical determinations should be made in the course of a soil survey can be disposed of in a few words if the answer is, "make the determinations requested by the soil surveyors." Judging from past experience, it would appear that two-thirds of the soil surveyors would like to have the samples they have collected subjected to all chemical tests that have been devised. The remaining third of the soil surveyors are of a still more inquiring disposition; they would add chemical determinations for which there is as yet no method.

This desire on the part of the soil surveyors for many chemical tests is prompted by the praiseworthy ambition to find out everything possible about the soils they are classifying and mapping. It may be criticized on the ground that it indicates in some instances a mistaken faith in the adequacy of existing chemical methods of soil examination. Even if it were advisable to make a large number of chemical determiations on soil survey samples, this is at the present time impossible. In the Bureau of Soils there are about seven soil surveyors to one soil chemist and in the state experiment stations there is probably a similar discrepancy between the number of surveyors and the number of chemists assigned to analytical work on soils. It should also be borne in mind that an active and inquiring soil surveyor can collect enough samples in a month to keep a rapid analyst occupied for a year.

It is of course futile to attempt to suggest what chemical determinations should be made in soil investigations in general. Suggestions might be made, however, regarding what chemical work it is advisable to undertake as a supplement to, or as an aid to, the regular work of distinguishing and mapping soils in the field. The chemical determiations that are to be proposed are suggested primarily for the purpose of adding laboratory characterizations to the field distinctions of the different soil types. They are not suggested with the idea of determining the proper fertilizer or cultural treatment of the soils surveyed, although they will inevitably throw some light on these subjects. Also, the determinations are not suggested with the idea that they should form the chief basis for classifying soils. The land must inevitably be divided into soil types mainly on the basis of what can be seen and distinguished in the field. The field distinctions can be explained and amplified to some extent, however, by chemical determinations.

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It seems that in characterizing the different soils chemically, the aim should be to obtain the more fundamental chemical characteristics, rather than reactions of the soils to empirical tests, no matter how valuable the empirical tests may be for predicting the cultural treatments of the soils. The ideal fundamental information that could be obtained would be a knowledge of the total quantity of each element in the soil and knowledge of how the elements are combined. This is a rather large order and the chemist is not equipped for filling it completely at the present time. However a good deal can be done.

The total quantity of each element in the soil can of course be determined by the fusion method of analysis. The fusion method gives more fundamental information about the soil than the old hydrochloric acid digestion method, since it gives something definite—the total quantity of each element present. The acid digestion method, which still seems to be quite generally used in Europe, is more or less of an empirical test, inasmuch as it does not appear to attack any specific part of the soil. Most of the material dissolved by the acid digestion method comes from the colloidal material, but the mineral particles are probably attacked somewhat and all the colloidal material is not dissolved.

In the past 30 years innumerable soil analyses have been made by the acid digestion method and a considerable number by the fusion method. Many analyses were made on samples of what used to be called surface soil and subsoil, or on less definite material, and a good many of the analyses can not be tied up with field descriptions of the soils which are sufficient to identify the soil types. In spite of all these drawbacks, these analyses have certainly added to our knowledge of soils in general. And while the chemist cannot point with pride to these analyses in the presence of a modern soil surveyor, the analyses have contributed something towards a distinction of soil types. They might be taken as a first attempt at a chemical characterization of soil types.

For the last seven or eight years the Bureau of Soils has been making complete chemical analyses of the various horizons in the soil profile. These new data are giving a much better characterization of soil types than the old analyses, chiefly because they were obtained on samples drawn in accordance with an improved method of distinguishing soils in the field.

Ultimate analyses of the soil horizons indicate the dominant features of broad groups of soils, but they do not distinguish individual soils satisfactorily. The gross chemical composition of a soil is merely a weighted average of many different soil materials. It is equivalent to a mechanical analyses which does not show the proportions of sands, silt, and clay but merely gives the average size of particle. Two soils which have very different field characteristics might contain similar quantities of silica, aluminum, iron, calcium, etc. This is because the elements are combined differently in the two soils. If individual soils or small groups of soils are to be characterized chemically, it is important to determine so far as possible the form in which the elements are present. The ultimate analysis of the soil horizons, therefore, constitutes only a part of what should be done towards characterizing the soil chemically.

The examination should show also what part of the total chemical constituents is tied up in the mineral particles and what part makes up the clay or colloidal material. The noncolloidal fraction of the soil (particles larger than 0.001 or 0.002 mm in diameter) and the colloidal fraction (particles smaller than 0.001 or 0.002 mm) are quite different in gross chemical composition, in chemical reactivity, and in physical behavior. The base exchange capacity of soils, the lime requirement, the pH, the adsorptive capacity for water vapor and gases, and the binding power of soils are all located largely or almost exclusively in the colloidal material. These two parts of the soil—the colloidal and noncolloidal materials—are also quite distinct genetically. The noncolloidal fraction is made up chiefly of those mineral particles of the parent material which have resisted decomposition during the development of the soil, while the colloidal material is made up chiefly of residues of the minerals that have decomposed. In other words, the noncolloidal fraction is the "not-yet" weathered soil material and the colloidal fraction is the product of weathering. Or, appropriating soil survey terms, the one could be called "rendzina" material and the other "mature" material.

It seems obvious that determination ought to be made of at least the gross chemical compositions of the mineral and colloidal parts of the soil material, if chemical characteristics of a soil are to be added to field characteristics and if laboratory determinations are to indicate what has occurred in the development of a soil from the parent material. In the case of the mineral part of the soil it is possible to proceed still further and determine by petrographic methods the proportions of the different minerals making up the mineral material. The chief objection to this more extended examination is the lack of soil petrographers, but in many cases these data will be needed to characterize the soil properly.

In the Bureau of Soils the composition of the colloidal material has been determined by first isolating it from the soil and then analyzing it. The isolation of the colloidal material is a time-consuming operation, but more rapid methods can doubtless be devised. When the whole soil and the colloidal material have been analyzed and the quantity of colloids in the soil has been determined by mechanical analysis or otherwise, the composition of the mineral part of the soil can readily be calculated.

These determinations which have been suggested—the gross compositions of the mineral and colloidal parts of the soil—will probably take at least twice as much time as an analysis of the whole soil, even if improved methods are developed; but the results should be far more valuable than a simple analysis of the whole soil.

If both the quantity and composition of the colloidal soil material are determined, the results of many other chemical determinations of the whole soil, such as pH, lime requirement, and exchangeable base capacity, can be predicted fairly well. Data on the properties of colloidal materials extracted from different soils, which have just been published,[3] indicate that a fair guess may be made at the pH of a soil if the analysis of the colloid is known. Also, if the quantities of colloid in soils as well as the kinds are known, the comparative lime requirements and base exchange capacities of the soils may be estimated fairly closely.

The pH of the soil or colloid correlates fairly well with the ratio of silica to alumina and iron in the colloid or with the total quantity of monovalent and divalent bases in the colloid. The more acid colloids usually have low ratios of silica to alumina and iron and contain a smaller quantity of the combined bases, calcium, magnesium, sodium, and potassium, than the neutral or alkaline colloids. The exchangeable base capacity of the colloid, or of the whole soil for that matter, also correlates fairly well with the silica-alumina-iron ratio of the colloid or with the content of total monovalent and divalent bases. Colloids with high silica ratios are usually high in exchangeable bases and the total exchangeable bases are usually one-half to one-third the sum of the total monovalent and divalent cations in the colloid.

The lime requirement of a soil, as determined by most of the 16 or more methods that have been proposed, is evidently conditioned by both the pH and the exchangeable base capacity. It seems that as characterizations of a soil, determinations of pH, exchange capacity, and lime requirement will be chiefly confirmatory of the more fundamental determinations of the composition and quantity of colloid in the soil. In many cases, however, these determinations may bring out minor differences in the colloidal material not revealed by the chemical composition.

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[3] ANDERSON, M. S., and MATTSON, S. Properties of the colloidal soil material. U. S. D. A. Bul. 1452. 1926.

RESULTS OF SOME PHYSICAL AND CHEMICAL STUDIES ON SOIL COLLOIDS[1]

M. M. McCool[2]

Several members of the Soils Section of the Michigan State College have done more or less work on soil colloids during the last decade (9).[3] These studies were undertaken and have been continued because they, with many others, believe that colloids play various and important rôles with respect to soil characteristics. It appears that the amount of colloids present in most soils is far greater than has been believed heretofore. Doubtless the incomplete dispersion of the colloids in the preparation of the soil samples for physical analysis accounted for these earlier views. Owing to the amount of colloids present and to their activities, it seems that they control, in the main, the chemical and physical reactions and properties of soils, such as base exchange, adsorption and retention of moisture, heat of wetting, evaporation of water, plasticity, and probably others (2, 8, 7).

It was formerly believed that the colloids existed in the soil as coatings around the other particles. In the light of recent knowledge (4) to the effect that the amount of colloids is much higher in soils than was previously considered to be the case, it appears that this is not always true. It is difficult to conceive of this condition existing in soils which carry, for example, 40% or more of colloids. It is probable, however, that the colloids exist as coatings around the larger particles in the B horizons of the strongly podsolized, sandy soils, and it is undoubtedly true that if it were not for the presence of these colloids in the B horizons the acreage of drouthy and unproductive land would be far more extensive. A few years ago the writer (6) brought out that the water-holding capacity of these horizons in certain of these types is much greater than that of either the leached horizons or the parent

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[3] Reference by number is to "Literature Cited," p. 296.

materials. Numerous questions remain unanswered. It may be cited, for example, that alfalfa and sweet clover grow satisfactorily without the use of lime on some Michigan soil types whose horizons have relatively low pH values and according to reports similar conditions exist elsewhere. A greater knowledge of soil colloids should furnish a better understanding of the soil.

PHYSICAL STUDIES ON DIFFERENT SEPARATES

The Ontonagon soil profile was selected for use in the study of differences in the various properties of the different sized particles that remain in suspension over a 24-hour period. About 2-pound samples from the A_1, A_2, and B_1 horizons were placed in 2-gallon jars and the dispersion of the fine materials was brought out by filling the jars with distilled water. The contents were vigorously agitated by means of a suction pump constructed of gas pipe and rubber stoppers. Twenty-four hours after agitation the liquid and suspended materials were siphoned off and run through the Sharples supercentrifuge. The same speed of centrifuging was maintained throughout these tests. The liquid was first passed into the bowl through the largest opening and the residue remaining in the bowl was separated into two portions, namely, the material at the base, No. 1, and that above which formed into a much thinner layer, No. 2. The liquid was then passed into the bowl through the medium sized tube and the residue collected and added to the samples of No. 2. Following this treatment the liquid was again run into the bowl through the smallest tube of the separator and the mass collected, No. 3. These processes were repeated 24 times, but since the solids collected on the last centrifuging were so small in amount they were grouped as shown in Table 1.

TABLE 1.—*Calories of heat developed per gram of material from Ontonagon soil horizons.*

Sample number	3rd dispersion	1st–11th dispersion	6th–11th dispersion	12th–23rd dispersion
A_1 No. 1	5.36	—	4.96	5.56
A_1 No. 2	9.36	—	8.21	8.44
A_1 No. 3	—	10.67	—	—
A_2 No. 1	4.94	—	4.88	5.24
A_2 No. 2	9.00	—	7.99	7.60
A_2 No. 3	—	11.73	—	—
B_1 No. 1	5.14	—	5.77	5.98
B_1 No. 2	9.53	—	8.69	8.42
B_1 No. 3	—	11.08	—	—

According to the data in Table 1 the colloids obtained from the different horizons by a similar method of procedure do not vary greatly with respect to the heat of wetting values, but there are very great differences in this respect between those obtained by different methods. The value of those grouped under No. 1 is approximately 5 calories per gram with a maximum variation of approximately 1 calory. The values for No. 2 range from 8.2 to 9.5 calories per gram and the heat of wetting values for those grouped under No. 3 range from 10.6 to 11.7 calories.

Remarkable differences were observed between the color and tenacity of the materials which collected at or near the base of the centrifuge tube and those higher up. Usually the former proved to be easily pulverized when dry and the remainder much more tenacious and horny-like in nature. In the case of the Ontonagon soil horizons the latter were likewise much darker in color. It appears, therefore, that the colloids that occur in a given soil horizon or even in different horizons may vary tremendously with respect to their physical characteristics.

These results appear to be in accord with those obtained a few years ago when the heat given off by different soils when brought into contact with water, alcohol, and ligroin, respectively, was determined.

In addition to the above studies fine materials were collected from different horizons of several soil profiles by dispersing them in distilled water, siphoning off the liquid 24 hours later, and evaporating it. Four hundred grams of the soil were placed in a liter beaker, the beaker filled with distilled water, and the fine material dispersed by agitating with a stirring rod. It was allowed to stand 24 hours and then siphoned off and evaporated in an oven. Each sample was dispersed ten times and each time the liquid was drawn off and added to the dry residue in the evaporate.

The heat of wetting determinations were made on these materials as well as on the original soil. Assuming that the heat of wetting is all due to the colloids (1) and that the soils extracted are representative of the mass in the soil, the percentage of colloids in the soil may be calculated by the formula $\frac{\text{H of W of soil}}{\text{H of W of colloids}} \times 100$. The heat of wetting of the soils and the dispersed materials, as well as the percentage of colloids, are given in Table 2.

It is to be noted that the colloids taken from the B horizons are more active than those from the other horizons and, in addition, quite large variations occur with respect to this property of the colloids removed from the different soils. The remarkably large amount of heat liberated when the colloids dispersed from the Roselawn and Chippewa B horizons are moistened with water appears to be due to the organic matter present in them.

TABLE 2.—*Heat of wetting of soils and dispersed materials.*

Soil type	Horizon	Calories of heat per gram of material		
		Soil	Colloids	Colloids %
Fox sandy loam	A	1.32	6.53	20.21
Fox sandy loam	B_1	2.50	9.04	27.65
Fox sandy loam	B_2	1.82	8.84	20.58
Hillsdale heavy sandy loam	A	0.93	5.91	15.73
Hillsdale heavy sandy loam	B_1	1.19	6.39	18.70
Hillsdale heavy sandy loam	B_2	1.24	6.07	20.42
Napanee silt loam	A	1.96	5.35	35.51
Napanee silt loam	B	2.93	7.35	41.09
Napanee silt loam	C	1.99	3.92	50.76
Kewaunee loam	A	1.38	6.22	22.18
Kewaunee loam	B	--	7.33	-
Kewaunee loam	C	1.72	4.61	37.31
Brookston silt loam	A	-	7.98	- -
Brookston silt loam	B	-	8.53	--
Brookston silt loam	C	-	5.53	
Roselawn light sandy loam	A_1	0.42	8.70	4.8
Roselawn light sandy loam	B_1	2.53	10.94	23.12
Roselawn light sandy loam	B_2	1.11	9.97	11.13
Chippewa light sandy loam	A_1	0.72	---	---
Chippewa light sandy loam.	B_1	2.66	19.93	13.34
Chippewa light sandy loam.	B_2	1.66	14.37	11.55
Onaway loam	A_1	0.49	4.20	11.66
Onaway loam	A_2	1.02	4.85	21.03
Onaway loam	B_1	2.41	6.68	36.07
Ontonagon silt loam	A_1	2.96	4.88	60.65
Ontonagon silt loam	A_2	3.21	5.57	57.63
Ontonagon silt loam	B_1	4.63	6.61	70.04

These results, as well as those of others, bring out that the colloids present in different soil horizons are much greater than was reported previously. Furthermore, some investigators (5) believe that most, if not all, the clay as determined by the mechanical analysis devised by the U. S. Bureau of Soils may be classified as colloids. If there is more of the fine materials than is indicated by the mechanical analysis, it follows there must be lesser percentages of the coarser separates in soils (3). An examination of the physical analysis of certain soil horizons furnished by the U. S. Bureau of Soils may be of interest in this connection.

In Table 3 are given the amounts of certain of the components of the A and C horizons of Kewaunee loam, A_1 and B_1 of the Roselawn sandy loam, and the A and B of the Ontonagon.

TABLE 3.—*The mechanical analyses of several soil samples.*

Soil type	Horizon	Fine sand	Very fine sand	Silt	Clay	Silt and clay	Colloids
		%	%	%	%	%	%
Kewaunee	A	38.2	12.2	27.6	6.6	34.2	22.1
	C	31.0	12.5	21.8	22.5	44.3	37.3
Roselawn	A_1	38.3	8.6	10.3	1.4	11 7	5.1
	B_1	35.5	7.0	4.8	5.0	9.8	23.1
Ontonagon	A	17.3	17.0	39.7	17.5	57.2	60.6
	B	11.1	9.5	23.2	51.1	74.3	70.4

The amount of colloids in the Kewaunee A horizon, as determined by the heat of wetting method, is very much greater than the clay reported and only about 12% less than the total quantity of silt and clay. In case of the C horizon the colloids are 7% lower in amount than the clay and silt. The Roselawn A horizon, according to the mechanical analysis, contains a very small quantity of clay and the clay and silt amount to 12.2%, whereas the colloids as determined by our method make up 5.1% of the mass. In case of the B_1 horizon the silt and clay comprise 9.8% and the colloids 23.1% of the sample. There is slightly more than 60% of colloidal material in the Ontonagon A horizon and about 70% in the B. In case of the former there is more colloidal material than the amount of silt and clay reported and approximately 4% less than there is in the latter.

It appears that if the results obtained by the standard method of mechanical analysis do not represent the true amounts of the fine sands, silt, and clay in all instances, it is largely on account of incomplete dispersion of the samples when shaken, and if such is the case it would seem that the proportions of the various grain sizes called for in the textural classification now in vogue need revision. It may be that there is a much smaller quantity of silt in nature than has been considered to be the case.

CHEMICAL STUDIES

The amounts of certain elements present in some of the above-dispersed materials and the pH values of different horizons of several soil types have been ascertained. Although additional determinations are in progress, it seems advisable to present certain of the results at this time. It should be recalled that in the dispersing of the fine materials nothing was discarded, the extracts being evaporated to dryness and the entire residue analyzed. It seems that this is important where soil samples are agitated and let stand in contact with large volumes of water, because considerable of the adsorbed bases may be removed from the colloids during this procedure.

The results of the determinations of nitrogen are given in Table 4. It is to be noted that the northern soils, Chippewa and Roselawn, carry large amounts of this element. It decreases with the depth of the horizons of the southern or Fox, Hillsdale, Napanee, Miami, and Brookston soil types. It appears that the organic matter in the B horizons of the strongly podsolized soils, in the main, owes its presence to the translocation from the surface, the biological processes having

TABLE 4.—*Nitrogen content of dispersed materials.*

Soil type	Soil horizon	N in dispersed material %
Fox	A	0.16
	B_1	0.09
	B_2	0.34
Hillsdale	A	0.16
	B_1	0.10
	B_2	0.14
Napanee	A	0.30
	B	0.12
	C	0.09
Miami	A	0.38
	B	0.17
	C	0.10
Brookston	A	0.30
	B	0.25
	C	0.10
Roselawn	A_1	0.95
	B_1	1.21
	B_2	1.00
Chippewa	A_1	1.04
	B_1	0.99
	B_2	0.68
Onaway	A_1	0.24
	A_2	0.19
	B_1	0.21
	C	0.06
Ontonagon	A_1	0.29
	A_2	0.13
	B_1	0.07

TABLE 5.—*Results of chemical analyses.*

Soil profile	Horizon	K_2O	Na_2O	P_2O_5	CaO	MgO	SiO_2
Napanee.	A	2.92	0.53	0.244	2.10	0.100	49.43
	B	3.93	0.66	0.109	2.12	0.841	58.82
	C	4.10	0.54	0.288	3.89	1.134	57.32
Brookston	A	3.40	0.29	0.292	— —	— —	54.93
	B	3.80	0.35	0.289	3.12	0.721	58.32
	C	4.23	0.72	0.289	3.18	0.999	57.59
Kewaunee	A	3.44	0.43	0.440	3.10	— —	50.69
	B	4.08	0.59	0.216	2.89	— —	54.53
	C	4.10	0.74	0.159	5.74	——	54.13
Onaway . .	A_1	3.18	0.44	0.118	3.32	1.161	63.79
	A_2	3.81	0.53	0.088	6.21	0.619	58.08
	B	3.84	0.43	0.048	2.51	0.663	53.74
	C	3.43	0.57	0.296	5.80	1.399	46.17
Fox	A	1.63	0.29	0.158	4.90	——	58.43
	B_1	1.54	0.44	0.330	4.36	0.943	56.00
	B_2	1.59	0.29	0.320	2.33	1.294	53.64
Hillsdale.	A_1	1.93	0.50	0.368	4.88	0.898	52.30
	B_1	2.32	0.27	0.307	3.20	1.412	52.03
	B_2	2.57	0.19	0.345	2.44	0.732	43.85
Stalwart .	A_1	3.24	0.82	0.370	6.48	0.601	51.52
	A_2	3.51	0.46	0.325	4.02	— —	57.24
	B	3.96	0.50	0.270	4.39	— —	46.65
Ontonagon.	A_1	3.78	0.44	0.162	1.98	0.425	61.34
	A_2	3.10	0.57	0.269	2.23	0.520	62.23
	B	3.69	1.26	0.137	4.76	0.478	60.70

been somewhat different from those that have taken place in the other soils.

The quantities of the oxides of potassium, sodium, phosphorus, calcium, and silicon in the materials dispersed from several soil types are given in Table 5. An examination of this table reveals a strikingly high potash content of each of the samples and, with the exception of the C horizon of the Onaway type and the A horizon of the Fox type, it increases with the depth of horizon. The phosphoric acid in each, with the exceptions of the A_2 and B horizons of the Onaway soil type, likewise is high in amount and usually the A horizons contain more of it than do the B horizons. The lime appears to be remarkably high in most cases, whereas the magnesium is much lower in amount. The silicon is lower as a rule than untreated samples of soil.

Soil colloids owe their existence to the weathering or decomposition and hydrolysis of the original or parent materials, such as minerals, rocks, and organic matter. It seems that colloids are formed wherever weathering takes place in the soil and it further appears that these processes are most active near the surface and consequently most of the colloids are formed there. Physical studies show, however, that they do not all remain at or near the surface, but are removed by wind and translocated by water and, in part, are redeposited lower down or in the B horizons.

Theoretically, the quantities of several bases, such as potassium, sodium, calcium, and magnesium, present in the colloids should be lower than those in the parent materials because of their relative solubility. The natural trend in the formation of colloids appears to be towards lateritic iron-aluminum-silicon ratios. Assuming that the most completely weathered colloids are removed from the A horizon, these should not be depleted ones. If, however, the colloids were formed appreciably faster than they were removed and if no adsorption of bases were to take place, these horizons would be low in bases. It appears that translocation does take place and it is probable that the colloids contain adsorbed bases.

Upon first consideration it would seem that the B horizons should contain colloids depleted to a large extent of their bases owing to the deposition of depleted ones from above, but on account of their great activity it is probable that they adsorb bases that are brought into contact with them and as a result may be relatively high in these elements. It appears that some of these may be brought from below by means of moisture as well as from above. Some of the possible sources of the latter are organic colloids and the salts that are liberated upon the decay of plant tissues. The above chemical analyses indicate that the colloids studied contain adsorbed bases.

It appears that the soil colloids during the processes of weathering of soils, owing to their great adsorptive capacity, act as valuable protecting agents with respect to several important elements that are utilized in the nutrition of plants. It is probable that it will be found upon further study that the lowering of the productivity of soils often involves changes in the soil colloids, especially those in the tilled layers.

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MICROBIOLOGICAL ANALYSIS OF SOIL AS AN AID TO SOIL CHARACTERIZATION AND CLASSIFICATION[1]

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INTRODUCTORY

The famous French chemist Berthelot once said "la terre végétale est regardée comme une chose vivante," "arable soil is considered as a living thing " With advance in the understanding of the rôle of micro-organisms in soil processes, this truth must come to be recognized more and more. Any system of characterization of a soil which is based merely on its physical makeup or even on its chemical composition will fail to give a correct idea of the dynamics of the given soil. A knowledge of the soil processes is intimately connected with the understanding of the nature and activities of the soil population.

The Polish bacteriologist Niklewski (14)[3] wrote some 15 years ago that the value of microbiological methods for soil characterization seems to be in a more exact study of the soil properties than is possible by the ordinary methods of physics and chemistry. Christensen (5) also stated that the microbiological condition of the soil, which reflects the qualitative and quantitative composition of its microflora and microfauna, can be considered as an expression of its chemical and physical condition.

The physical and chemical methods of soil analysis are comparatively too crude to determine the presence, both qualitative and quantitative, of the various soil factors which control plant growth. At best the results obtained by those methods supply information concerning only the static condition of the soil, namely, its mechanical composition, presence and concentration of certain nutrient elements, etc., but not its dynamic condition, or the processes which go on in the soil constantly. To characterize a soil, it is not merely sufficient to know what it consists of, but also what changes these constituents may undergo. In other words, a soil should be characterized not only by what it is composed of, but also by the changes constantly going on and even by the rates of these numerous changes. This is important if information is to be obtained concerning the productive capacity of a given soil. Moreover, this information is valuable in obtaining knowledge of the past history of the particular soil and its probable future development, whether left untreated or subject to certain treatments. A study of the microbiological activities in the soil (outside of the actual growth of plants, a method very lengthy and full of pitfalls) may supply the means of obtaining a certain insight into this dynamic condition and may aid in recognizing the processes whereby the inert complexes (as far as immediate plant utilization is concerned) may change into plant nutrients.

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[3] Reference by number is to "Literature Cited," p. 309.

Chester (4) was the first to suggest a formula for determining the coefficient of the "zymotic-efficiency of the soil" which would express the results of a bacteriological analysis of soil in a qualitative-quantitative manner. "Zymotic efficiency" was considered to be the product of the number of bacteria found in the soil by the amount of transformation (ammonia formation from peptone, etc.) that each of these bacteria could accomplish in a given period of time The fact that only very few of the activities of soil bacteria could be measured by the methods employed by Chester and those following him; the lack of recognition of the great abundance of other microorganisms in the soil, besides the bacteria, capable of producing, in many instances, similar changes; the lack of adequate methods for measuring the processes carried out by the numerous organisms in the soil; and, finally, an inadequate understanding of these numerous processes, prevented Chester himself and those following him from developing further the idea of distinguishing soils on the basis of the biochemical processes resulting from the activities of their microscopic population. Without going into a detailed review of the progress of knowledge of soil microbiology, it is sufficient to say that there is adequate information on this subject at the present time to crystallize our ideas and at least make an attempt at a selection of a series of methods for the purpose of soil differentiation which would aid in its characterization and classification.

To indicate the practical possibilities of the interpretation of results thus obtained, it is sufficient to call attention to the fact that at the last International Congress of Soil Science in Rome a paper was presented by Dr. Doerell(8) in which definite recommendation has been made that the system of taxation of farm land be based on the potential productive capacity of the soil as measured by the amount of carbon dioxide given off from a definite quantity of soil, in a given period of time, and at a definite set of environmental conditions, i. e., that the soil should be taxed not on the basis of what the farmer is able to obtain from it but on a comparative basis of its potentiality. This could be obtained only by measuring directly a process which results from the activities of micro-organisms in the soil.

METHODS

The literature of the subject of soil microbiology abounds in discussions of old and new methods for determining the nature, abundance, and activities of micro-organisms in the soil. There was a time, and that not so very long ago, when it was believed that it was sufficient to add a little soil to a sterile peptone solution or to some other medium, incubate for a few days, then distill over the ammonia or measure some other change produced to obtain a measure of the microbiological activities of the soil. In other words, those interested in practical soil problems believed that certain tentative soil processes have passed the experimental stage and could be used for routine determinations, just as so many chemical methods of analysis. The expectations thus aroused were at the very beginning doomed to lead to disappointment. The soil is too complex a medium and its microflora and microfauna form too complex a population to be able to measure the changes taking place by a few simple procedures. So that even at the present time the most important problem of the science of soil microbiology is the need of new methods.

Considerable information has accumulated concerning the nature and occurrence of the organisms found in the soil, methods of isolation, identification, and determination of biochemical activities under controlled laboratory conditions. Unfortunately, comparatively little is known even as to the actual rôle of these organisms in the soil itself under natural field conditions. The determination of the sum total of the activities of micro-organisms in the soil, which would enable us to obtain a clear picture of the processes going on there, is thus far impossible. The results obtained by the various methods of study now in use throw light either upon the activities of one or more definite groups of organisms, upon one definite process, or upon the formation of a certain intermediate or final product of microbial metabolism. The assumption is thereby usually made that the activities of the other soil organisms run parallel with the one process or organism under consideration or that the determination of a definite product of microbial metabolism gives the resultant of the sum total of the activities of the soil microflora and microfauna. Frequently, of course, this may be altogether wrong.

These considerations will help to estimate properly the results obtained by the procedures discussed in the following pages.

Of the various methods suggested at different times for measuring microbiological activities in the soil, several have been found to give comparable results so that they can be used as an index of soil processes in general, and, therefore, might be suggested as an aid in soil characterization Many other methods could be added to these, but the results obtained by them are still a matter of controversy and the methods are still subject to further study. Even those methods which are recommended here are still open to criticism, since they may give varying results in the hands of different investigators. However, the principles upon which they are based are certainly above criticism and, although the methods themselves may be modified in course of time and no doubt will be, the results obtained by the use of these methods, especially when it is considered that they are only relative in importance, offer a sufficient basis for the separation and characterization of different soils.

1. RELATIVE ABUNDANCE OF MICRO-ORGANISMS IN THE SOIL

No other method of analysis has called forth more controversy than the determination of the numbers of micro-organisms (largely bacteria) in the soil. Some investigators (11) do not consider the results obtained by this method as having any bearing at all upon soil fertility processes. On the other hand, results have been obtained (21) concerning the relative abundance of soil organisms which point definitely to the fact that different soils show distinct differences in the quantitative composition of their flora. Such contradictory opinions concerning the very abundance of the soil population is due to the great variations in the methods employed in determining the number of bacteria and other micro-organisms of the soil. It was found that the use of synthetic media and a definite set of conditions will give as comparable results as can be expected in a biological experiment. Unfortunately, the plate method allows the determination of only a small fraction of the soil population. Even the organisms that are capable of developing on the plate may grow into colonies only to a limited extent, so that of each dozen types of organisms present in the soil only one may be able to grow on the particular medium used in the preparation of the plates; and of each 100 cells of this very organism, only 1 to 10 may actually grow and devlop into colonies, so that instead of billions of organisms per gram of soil we obtain only millions. Then the plate method does not allow the separation of vegetative from reproductive cells in the case of fungi. However, the assumption that these limitations hold true of all soils and that the micro-organisms actually developing on the plate represent similar phenomena in different soils allows a definite amount of emphasis to be laid upon the results obtained by the plate method.

To obviate the difficulties of this method, the direct microscopic examination (7) of the soil has been suggested. This as well has its limitations. It is sufficient to mention the fact that this method does not distinguish between dead and living cells, it does not allow an accurate observation of certain types of organisms which stain only very faintly or with difficulty, such as spirochaetes and protozoa, and it may prove of considerable difficulty in the hands of the inexperienced worker. There is no doubt, however, that even an approximate determination of the numbers of micro-organisms in the soil by the microscopic method will give results of great value and perhaps of more direct application than the results obtained by the plate method, even under the conditions suggested. Both methods may, therefore, be utilized for the present for the purpose of obtaining an idea of the abundance of the soil population, the results obtained by one method supplementing in a way the results obtained by the other. The microscopic method gives the total number of bacteria in the soil and allows differentiation between cocci or short rods, large bacilli, and Azotobacter cells. A fair idea can also be obtained of the abundance of actinomyces and fungus mycelium. The plate method shows a much smaller number of organisms for a definite unit of soil, but it gives a fair idea of the abundance of the organisms which are capable of developing on the plate. An acid soil will give a large number of fungi and a low number of actinomyces; an alkaline soil or an arid soil will contain a flora rich in actinomyces and low in fungi. One must mention here that the animal population of the soil is not accounted for by either of the two methods and must be determined by special methods.

Without going into a detailed review of the methods themselves, it is sufficient to present certain data which would indicate that soils can be differentiated on the basis of the number of organisms obtained by the microscopic and plate methods.

Richter (15), using the method of Winogradsky (27), suggested that three groups of bacteria could be distinguished, namely, cocci (C), bacilli (B), and Azotobacter cells (A). A forest soil contained at the surface 1,379,000,000 cocci, 1,212,000,000 bacilli, and 156,000,000 Azotobacter cells per gram. Taking the number of cocci (and short rods) in the forest soil as 100 and expressing the numbers of the other groups and in other soils on this relative baisis, the following results were reported.

Soil type	Depth	C	B	A
Forest	Surface	100	88	11
Forest	10 cm	100	47	8
Chestnut	Surface	63	27	14
Chestnut	10 cm	57	11	15
Sandy	Surface	38	18	11
Sandy	10 cm	38	14	11

These results show that cocci (and short rods) form the most abundant group of bacteria. Bacilli are very abundant in forest soils and relatively less abundant in a cultivated black soil and in sandy soils. Azotobacter is especially abundant in the cultivated black soil The cocci and Azotobacter cells are largely found upon the colloidal particles of the soil in the form of colonies surrounded by slimy capsules. The bacillary forms are present in the soil solution, but frequently form colonies on the surface of decomposing organic matter

A definite relation has been obtained (21) between the productive capacity of the soil and the numbers of bacteria as determined by the plate method, using a series of plats differently treated for a period of 15 years where definite differences seem to have been established as a result of the treatment. The parallelism was quite evident

For the benefit of those, who are interested in the fact whether sodium nitrate or ammonium sulfate offer a better source of nitrogen for plant growth, the results of two experimental plats from the New Jersey series may be cited One plat receives sodium nitrate and minerals (9A) and the other receives an equivalent amount of nitrogen as ammonium sulfate, together with lime and minerals (11 B).

	9A	11B
Reaction of soil	5.5	5.8
Total number of bacteria and actinomyces	10,113,000	9,500,000
Actinomyces, %	25	26.5
Fungi, number	46,450	39,100
Total crop yield for 15 years, pounds	50,488	53,826

These results tend further to indicate the correlation between the crop yields and the number of micro-organisms found in the soil.

2. EVOLUTION OF CARBON DIOXIDE

The practical agriculturist is not so much interested in the total content of chemical elements that could be utilized by plants if they were in an available form as in the availability of these elements or the rapidity with which they can be liberated and made available for the growth of cultivated crops. This information can be obtained only when the activities of the micro-organisms are studied under given conditions and as a result of treatment. There is no better single index of these activities than the amount of CO_2 produced by a given quantity of soil (1 kgm.) when placed at optimum conditions (25°C) for a given period of time (1 or 14 days). This is due to the fact that CO_2 is the most common product of decomposition of organic matter in the soil and that it is a final product. In the case of normal cultivated soils the evolution of CO_2 will be accompanied by a parallel liberation of nitrogen as ammonia and minerals. In the case of a virgin, non-cultivated soil certain specific treatments, (drainage, liming, addition of phosphates and potassium salts or nitrogen) which lead to an increase in the evolution of CO_2 will also lead to a greater liberation of the nutrient elements and to the more rapid formation of a normal field or garden soil.

The use of oxidation processes in the soil, either the absorption of oxygen or the liberation of CO_2, for measuring microbiological activities in the soil, has been suggested by Russell (16), Stoklasa (17), van Suchtelen (20), Konig and Hasenbaumer (10), Neller (13), and others. The amount of CO_2 produced was found to depend on the amount and nature of organic matter, physical and chemical condition of the soil, and activities of micro-organisms. It was even concluded (20) that the determination of CO_2 evolution furnishes a better means of estimating the bacterial activities in the soil than the numbers of bacteria. Treatment of soil was found to have a decided influence upon the nature and amount of soil organic matter as indicated by the degree of its decomposition. A definite correlation was obtained (26) between the crop-producing capacity of a given soil and its microbiological activities, including the evolution of CO_2 from the soil itself as well as the ability of the soil population to decompose organic matter as indicated by the evolution of CO_2. However, even this index is not absolute and specific for a particular soil, but the results obtained depend upon (a) the number and kind of organisms present, (b) amount of organic matter in the soil, (c) the composition of this organic matter and the degree of decomposition, (d) soil aeration, (e) moisture content, (f) physical condition of the soil, (g) chemical composition, (h) soil reaction, and (i) kinds of plants grown (19).

3. NITRIFYING CAPACITY OF THE SOIL

Among the various elements required for the growth of higher plants nitrogen is apt to be the most limiting one. When organic matter is decomposed in the soil the nitrogen-carrying complexes undergo a series of changes the final product of which is ammonia. In most soils, especially in normal aerated soils, the ammonia is rapidly changed to nitrate so that only traces of the former are ever found in such soils. The nitrate tends to accumulate, unless it is washed out, used up by higher plants, or reduced by micro-organisms under certain conditions. When a certain quantity of a normal soil is placed in the laboratory under optimum conditions, nitrate will begin to accumulate, the rapidity of accumulation depending on the nature of the soil and rapidity of decomposition of the organic matter. When the soil contains an excess of carbonaceous or energy bearing materials, it will take considerable time before the nitrate will begin to accumulate. The rapidity and amount of nitrate accumulation as a result of soil treatment can readily indicate the need of modification of a given soil in order to make it productive Results obtained by the use of this method run parallel with the evolution of CO_2 and the numbers of micro-organisms (22, 26).

A correlation between nitrification and soil productivity has been brought out by the work of a number of investigators in this country and in Europe. Burgess (2) found it to be the most accurate biological method for predicting probable soil fertility. According to Fischer (9), nitrification in soil can be used for soil characterization.

4. CELLULOSE-DECOMPOSING CAPACITY OF A SOIL

When cellulose is added to soil it is attacked readily by various groups of organisms, including fungi, bacteria, and actinomyces. These organisms utilize the cellulose as a source of energy and transform a certain amount of the carbon into microbial protoplasm. There is a definite ratio between the cellulose decomposed and microbial cell substance synthesized in a given period of time, the ratio varying somewhat with the organisms active in the decomposition of the cellulose and with the environmental conditions. For the synthesis of the cell substance definite amounts of nitrogen are required. In other words, within certain limits, there is a definite ratio between the amount of cellulose that will be decomposed in a given soil and the nitrogen that is made available to the microorganisms decomposing the cellulose. If the cellulose is in excess, the greater the concentration of available nitrogen the greater is the amount of cellulose decomposed in a given period of time. This can be determined either by the evolution of CO_2 or by the actual extraction and determination of residual cellulose. The more fertile a soil is, the more rapid the decomposition of the soil organic matter and the liberation of nitrogen and the more rapid will be the decomposition of the cellulose added to the soil in the form of filter paper or straw. The amount of cellulose decomposed in a given soil in a given period of time can thus serve as an index of the total amount of nitrogen that would become available in such a soil in the particular period of time (23).

This relationship is independent of the actual amount of cellulose decomposed in a given soil. The quantities of cellulose decomposed may differ with different soils, but the relationship between the cellulose decomposition, CO_2 evolution, and nitrogen assimilation is practically the same.

A definite relation between the available nitrogen of the soil and the amount of cellulose decomposed in a given period of time has also been obtained by Christensen (6), Niklewski (14), and Barthel (1).

5. NITROGEN FIXATION AND DEVELOPMENT OF AZOTOBACTER

The principles upon which the various methods for measuring the development of nitrogen-fixing organisms and the nitrogen-fixing capacity of the soil are based consist in the stimulation of these organisms by the addition of an excess of available energy. When cellulose is added to the soil it will remain undecomposed, if there is no available nitrogen, since the various fungi, bacteria, and actinomyces which carry out the process of cellulose decomposition in the soil cannot do so unless they are supplied with available nitrogen and to a lesser extent with phosphorus and other minerals. When a soluble carbohydrate, like glucose, mannite, or even starch, is added to the soil, organisms capable of obtaining their nitrogen from the atmosphere, namely Azotobacter in some soils and *Bac. amylobacter* in all soils, will immediately develop. In other words, the lack of combined and available nitrogen in the soil will not serve as a hindrance to the development of these organisms, for in the presence of available energy they will draw upon the inexhaustible supply of gaseous elementary nitrogen. The only limitation to the development of these organisms, in the presence of available energy, is the supply of available phosphorus in the soil, since there seems to be a more or less definite ratio between the nitrogen and phosphorus content of the protoplasm of these organisms (18, 25).

The determination of the nitrogen-fixing capacity of the soil has, therefore, two specific ideas in view, namely (a) the determination of the abundance and activities of nitrogen-fixing bacteria in a given soil, and (b) the determination of the amount of available phosphates in the particular soil

Winogradsky (28) recently suggested several tests for measuring the fertility of the soil on the basis of the response of development of Azotobacter. When some mannite is added to the soil spontaneous development of Azotobacter may or may not take place. When a definite quantity of soil is placed upon the surface of a silica-gel plate and incubated for 120 hours at 30°C, the abundance of Azotobacter will be indicated by the amount of the relative nitrogen fixed. An active soil will fix 20 mgm. of nitrogen per 2 grams of mannite on this plate A definite parallelism between the abundance of Azotobacter in the soil, or between the amount of nitrogen fixed in the soil in a given period of time per unit of energy-bearing material decomposed, and the fertility of the soil has been observed also by a number of other investigators.

Christensen (6) and Stoklasa (18) suggested the use of the intensity of growth of crude cultures of Azotobacter in mannite solutions, free from phosphorus (or calcium), to which a definite amount of soil was added, as an index of the content of available phosphorus (or calcium) in the given soil. All agricultural soils contain nitrogen-fixing organisms, while only a fraction of these soils contain Azotobacter The abundance of this organism can be determined by the microscopic method suggested by Winogradsky (28)

6. THE AMOUNT AND NATURE OF ORGANIC MATTER ("HUMUS") IN THE SOIL

It is fully recognized that a difference in the amount of organic matter in the soil and a difference in the nature of this organic matter will greatly influence the type with which a certain soil will be classified. Soil organic matter is thus of prime importance in soil clasification, influencing not only such relatively trivial characteristics as the color and odor of soil, but also such important properties as moisture-holding capacity, reaction, buffer content, not to mention the productive capacity of the soil. The nature of this organic matter and its rôle in the soil can be fully understood only when its origin is known. Without going into a detailed review of this complicated subject, it is sufficient to say that the latest researches tend to throw light upon this subject, once the rôle of micro-organisms in the transformation of this organic matter is understood (24, 29).

Attention will be called here merely to the determination of the so-called "humus" in the soil, assuming under this term that part of the soil organic matter which is soluble in alkali solutions on prolonged treatment by the use of heat and under pressure. The soil organic matter thus extracted (using 4 %NaOH solution, 100 cc per 50 grams of soil, extracting at 15 pounds pressure for 30 minutes, filtering, then repeating the extraction and combining the filtrates) can be divided into (a) that part which is precipitated by an excess of hydrochloric acid, (b) that part which is soluble in alkalies and in acids but precipitated at a definite pH value, and (c) that part which is made soluble in water as a result of the alkaline treatment. Without going into a discussion of the details of the methods, it is sufficient to point out that the content of the first two fractions in various soils (Table 1) and the nitrogen content of the three different fractions is quite characteristic of the type of soil and of the nature of its nitrogen complexes. A knowledge of these can throw sufficient light upon the origin of the particular soil and aid greatly in its classification.

The results obtained from a microbiological analysis of soils can help greatly in characterizing a soil, not in its mechanical, physical, or chemical properties but in its dynamic behavior, namely, in the rapidity of transformation of organic and inorganic substances in the particular soil at a given set of conditions. These results show not only a definite correlation between the activities of micro-organisms and soil fertility, but also a relation between the genesis of the soil or past processes which have led to the formation of the particular soil and its present microbiological condition.

The author does not want to suggest in the least that an attempt is being made at standardizing the above or other methods of microbiological soil analysis. The subject of micro-organisms and their activities in the soil is still in an experimental stage and we possess few comparative data on the behavior of micro-organisms in different soils and on the influence of soil type upon the nature and activities of these organisms. The data obtained by the above methods will show (a) whether the soil is a favorable medium for the growth of micro-organisms, (b) how abundant the amount of soil organic matter is and whether it is in an active or in an inactive stage of decomposition, (c) how rapidly and to what extent the nitrogen of the soil can become available to higher plants, (d) how abundant is the amount of phosphorus in the soil that can become available for plant growth in a given period of time, (e) the calcium need of the soil, etc.,

TABLE 1.—"*Humus*" *content of different soils in 100 grams of dry soil*

Soil type	Treatment	α-fraction		β-fraction		N content of solution
		Yield	N content	Yield	N content	
		mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm. N*
Sasafrass	Manured (5A)	766	26.0	1,894	22.9	36.1
Sasafrass	Unmanured (7A)	248	8.2	1,468	16.2	19.4
Sasafrass	Manured and limed (5B)	674	23.0	1,702	19.8	41.8
Sasafrass	Unmanured but limed (7B)	293	9.9	1,863	14.6	31.6
Peat, brown		33,600	708.0	—	—	706.0
Muck, black		26,220	482.0	—	—	578.0
Forest, humous layer		39,800	—	—	—	—
Cuban clay, unproductive surface		374	12.8	1,406	13.1	—
Cuban clay, subsoil		0	0	—	—	—
Cuban red clay, productive surface		585	20.8	2,678	25.4	—
Cuban red clay, subsoil		154	6.3	2,238	19.2	—
Cuban alluvial clay, surface		904	26.6	1,253	18.7	—
Cuban alluvial clay, subsoil		570	14.9	1,461	9.5	—

etc. This and other information is more than enough to justify a study of microbiological analysis of soil from the point of view of soil characterization and classification. While the mechanical, physical, and chemical analyses would define the soil type, the microbiological analysis would define the dynamic processes in the particular soil and its ability to support plant growth.

SUMMARY

Whatever practical information may be derived from the microbiological analysis of soils, the primary purpose of such analysis would be its fundamental scientific importance. The methods of analysis should be of such a nature as to give an accurate picture of the abundance and activities of the soil population. Much remains to be done before methods can be proposed which might be standardized. Very little is known of the soil population as influenced by the mechanical composition, physical and chemical condition of the soil, climatic and seasonal variations, and a host of other factors. The soil population is so sensitive to changes in nutrition and to environmental conditions that we may never be able to draw an exact picture of the microbiology of given soil types, but the very fact that it is so sensitive an index of changes taking place in the soil makes a knowledge of the microbiological condition very valuable for the characterization of soils. Where other information obtained by mechanical, physical, and chemical soil analysis may give the gross characteristics of a soil, the information on the microbiological condition will tend to bring out the finer differences not seen by the naked eye and not measured by chemical reagents. The information thus obtained may not help so much in the classification of soils as in explaining the existence of certain soil characteristics.

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THE GRUNDY SOILS OF NEBRASKA[1]

F. A. HAYES[2]

The purpose of this paper is to enumerate and describe the more constant characteristics of the virgin Grundy soils of Nebraska and to describe the more important variations in the zones of maximum compaction and lime accumulation. This is done in the hope that it may lead to further and more intensive profile studies and to more definite information upon which to base soil correlations.

LOCATION

There is an area of about 4,000 square miles of Grundy soils in Nebraska, distributed in the southeastern and east central parts of the state as a large body and outlying areas. (See map.) Within this region are numerous soils of other series including those of the Marshall, Holdrege, Colby, and Knox groups, as well as a great variety of alluvial soils such as Wabash, Cass, Sarpy, Lamoure, etc. South of the Platte Valley, however, and locally north of this valley, those soils having characteristics common to the Grundy group dominate and the profile seems to represent the final result of the soil-forming processes, as governed by the climatic and vegetative environment, in this portion of Nebraska.

The boundary of the Grundy area, as indicated on the map, is more or less general This investigation has been too limited to determine a definite boundary on the western and northern borders where the Grundy merges into adjacent soil areas. On the east, however, it has been possible to bound the soil with considerable accuracy because the topography changes quite abruptly and the loessial and glacial materials are rather sharply defined. The southern boundary, which extends into Kansas, has not been definitely determined.

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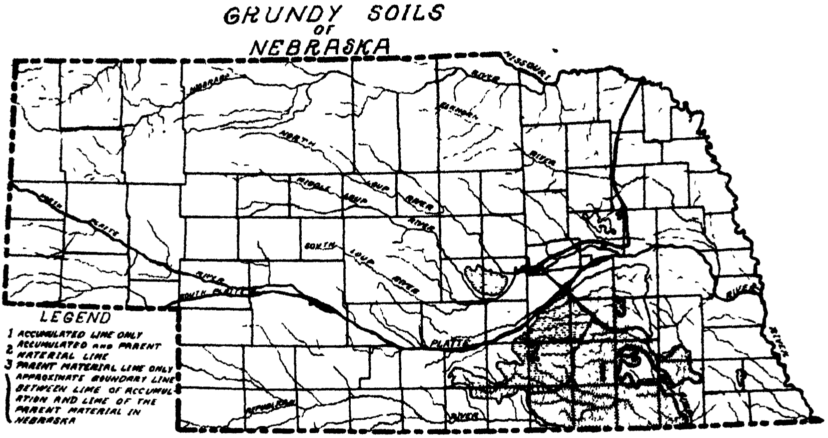
[2] Soil Surveyor, Bureau of Soils, U. S. Dept. of Agriculture. In the investigation of this problem, the writer has had the helpful assistance and guidance of Dr. C. F. Marbut and T. D. Rice and the assistance of A. W. Goke and M. H. Layton of the Bureau of Soils, and men connected with the state survey. Dr. G. E. Condra, Director of the Nebraska Soil Survey, has been in close touch with the work, furnished most of the transportation, and edited the manuscript.


GRUNDY SOILS OF NEBRASKA
LEGEND
1 ACCUMULATED LIME ONLY
2 ACCUMULATED AND PARENT MATERIAL LIME
3 PARENT MATERIAL LIME ONLY
APPROXIMATE BOUNDARY LINE BETWEEN LIME OF ACCUMULATION AND LIME OF THE PARENT MATERIAL IN NEBRASKA
MISSOURI
PLATTE
1
2
3

TOPOGRAPHY AND OCCURRENCE

The Grundy of Nebraska is confined to nearly level upland plains in which small basin-like depressions are a characteristic feature. An almost flat relief seems to be one of the dominant requirements. The soil seldom occurs on a topography stronger than undulating and the greater part has a flat to gently undulating surface. In areas where stream erosion has altered the generally level surface, the Grundy is entirely absent or occurs only upon the areas least dissected.

The soil seldom extends more than a short distance down slopes It usually begins to disappear several rods back of the border where the plain gives way to slopes leading to drainage ways. Extremely narrow divides, although having an almost level surface, are usually devoid of Grundy soil. There is practically no relief on the normal Grundy. Such drainage ways as occur, except the most shallow sags, are bordered by other soils or by Grundy in the process of change.

DRAINAGE

Under-drainage is poor. The surface run-off, while adequate, is slow. There is sufficient slope, however, to divert the surplus surface waters into some invading drainage system or into one or another of the numerous basin-like depressions, and the land does not become too moist for crop production. The soil is seldom subject to direct stream erosion. It recedes as streams encroach its area, but this recession is usually accomplished through a change in profile characteristics, resulting in either a Marshall or a Holdrege soil.

Practically all of the Grundy area in Nebraska drains to the south and east into the Big Blue, Little Blue, and Republican Rivers. The small bodies north of the Platte drain eastward into that stream.

ALTITUDE AND SLOPE

There is a range in elevation of about 850 feet within the area occupied by Grundy soils. The lowest, about 1,300 feet above sea level, is in some of the outlying bodies in the southeastern part of the state and the highest, about 2,150 feet, is in the western extremity of the Grundy region. Probably 75% of the soil, however, lies between 1,650 and 1,850 feet above sea level. Broadly speaking, there is a general slope to the southeast of 6 to 8 feet per mile.

CLIMATE

The climate, according to the U. S. Weather Bureau records, is quite uniform. The mean annual rainfall varies only 2.86 inches, being 31.5 inches at Tecumseh, near the eastern border, and 28.64 inches at Minden near the western edge. Most of the rain falls from May to August, inclusive. The mean annual temperature varies only 3.6°F, being about 48°F at David City in Butler County and 51.6°F at Minden.

NATIVE VEGETATION

The prevailing native vegetation throughout the eastern part of the Grundy area is distinctly of the tall grass sod type. Little blue stem (*Andropogon scoparius*), spear grass (*Stipa spartea*), June grass (*Koelcria cristata*), gold stem (*Andropogon nutans*), and side oats grama (*Boutelous racemosa*) seem to dominate on the uplands. In the western part, however, the tall grasses gradually give way to the short grass species, chiefly grama and buffalo.

PARENT SOIL MATERIAL

Most of the Grundy is on loess plains[3], but some outlying bodies in the southeastern counties are in the drift hill area, either upon loess-capped divides or underlain by material decidedly loess-like in appearance. No gravel or boulders occur above depths of 10 or 12 feet within Grundy areas.

METHOD AND EXTENT OF OBSERVATION

The Grundy soils have been mapped during a period of 12 years or more in Nebraska. However, no special attention in regard to detailed profile studies and the relation of the different horizons to one another was made until recently.

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A special study of the virgin Grundy soils began early in the present year and continued intermittently until the latter part of October. During this period the Grundy profile has been examined to a depth of 8 feet or more in 85 selected localities. In many of these, pits were dug to 6 or 8 feet and the soil auger was used to extend the depth to a minimum of 12 feet. The other examinations were made either in road cuts, building excavations, by means of an 80-inch soil auger, or a combination of these. Observations were made entirely in the field. Profile data were recorded and in many cases samples were taken for later study.

PROFILE DESCRIPTION

STRUCTURELESS MULCH

The Grundy soils of Nebraska have a mature profile. The first, or surface layer, consists of a structureless mulch, dust-like when dry, ranging in thickness from a mere film to about 2 inches. It varies in color from grayish brown to dark grayish brown, but is seldom black or even very dark grayish brown when compared with the color standards now used by the field men. The texture varies from very fine sandy loam to silt or even silty clay, but probably averages a very fine sandy loam.

LAMINATED HORIZON

The second in the profile is the laminated or platy zone. It is remarkably persistent throughout the area of Grundy soils. This zone is a very dark grayish brown or almost black friable silt loam to very fine sandy loam. It is usually as dark or darker than any horizon above or below. When pulverized or sliced through, it retains its original shade to a remarkable degree, probably indicating that the dark coloration has thoroughly permeated the soil particles.

The soil aggregates are disk or plate-like forms, which overlap one another in such a manner as to give the characteristic laminated or platy appearance to the horizon. The disks are seldom thicker than 1/16 inch and so fragile as to make it almost impossible to determine their form and size. They seem to be thickest in the center and to taper to a thin edge.

The laminated horizon is thickly matted with grass roots. Material removed from the zone breaks naturally into more or less flattened granules to which the roots cling tenaciously.

The horizon averages about 3 inches in thickness, varying from ½ inch to over 6 inches. Some observations indicated that it may be thicker in the territory immediately south of the Platte and thinner than the average in the eastern part of the Grundy area, but the data are not sufficiently complete to warrant a definite conclusion. Under correct moisture conditions the laminated horizon is sharply defined, due chiefly to its peculiar structure and to some extent to its unusually dark color. In a moist condition it is almost obscure.

GRANULAR HORIZON

The third persistent horizon in the Grundy is the granular zone. It varies in thickness from 10 or 12 inches to about 2 feet. This zone is characterized by some form of granulation or arrangement of the soil particles in such manner as to produce more or less irregular shaped aggregates, usually with well-rounded edges and corners. These aggregates may be of approximately the same size and shape throughout the horizon but are more often smaller in the upper than in the lower portion. They seldom exceed ½ inch in diameter at any point and usually average less than ¼ inch in the upper part of the zone and between ¼ and ½ inch in the lower.

The more finely granular layer often contains an abundance of well-rounded worm casts. In a few places this layer was observed to be composed almost entirely of worm cast groups, many of which retained their cystlike coverings. In most places, however, the cysts had become partly or entirely destroyed and most of the casts had merged or otherwise become so distorted in shape as almost to lose their identity. Borings, or twisted rod-like forms, probably representing old filled-in insect or worm holes, are common throughout the horizon and often very numerous in the lower portion. It is concluded, on the basis of observations made, that the granular horizon is one in which the structure produced by worm and insect action has been little modified. Grass roots are abundant in the granular zone, the rootlets clinging to the finer granules.

The color of the zone, although usually lighter than that of the laminated horizon, remains very dark, especially in the upper part. The intensity of shade decreases with depth and the zone is grayish brown to dark grayish brown near the base. The color is seldom uniform throughout, but is usually a mixture of very dark grayish brown or black intrusions in a slightly lighter matrix. There seems to be no definite arrangement of the different colors. The darker shades extend downward along old filled-in worm, root, or insect holes and chains of granules or occur as apparently disconnected splotches or spots where the organic matter has evidently concentrated around individual soil aggregates. In most places the darker intrusions are so numerous in the upper part of the zone and blend so gradually with the remainder of the soil that the color at first glance appears quite uniform. In the lower portion the darker shades are less pronounced, but stand out clearly in the lighter colored matrix.

When pulverized or cut through, the material of the granular zone usually becomes grayish brown or considerably lighter than that of a broken face, probably indicating that the organic matter does not penetrate the granules so deeply as in the laminated zone but occurs more as a surface film or coating.

Columnar form seldom occurs in the granular horizon. The upper portion is quite mellow and averages a silt loam or heavy silt loam in texture. In the lower part the clay content is usually greater and the material is a moderately compact silty clay loam

The three horizons described are quite uniform throughout the area of Grundy soils in Nebraska. They vary slightly in color and texture and considerably in thickness, but are usually present, occupying the same relative positions in the profile, and remain remarkably constant in structure

MAXIMUM COMPACTION HORIZON OR CLAY PAN

The remaining horizons of the profile display considerable variation in different localities and the lower one may disappear entirely in portions of the Grundy area. The upper member, or counting from the surface the fourth zone in the profile, is the one of maximum compaction. This zone persists in the Grundy soil with variation in its characteristics. It is denser than the corresponding zones in the Holdrege and Marshall soils.

BROWN CLAY-PAN

Throughout most of the Grundy region, the zone of maximum compaction resembles a clay-pan, being a moderately to extremely dense silty clay or clay. Its depth is 15 to 24 inches and the thickness is between 4 inches and 2 feet.

Columnar form may or may not occur in this horizon, but is usually faintly developed in the upper part and quite pronounced in the lower The columns are of various sizes, seldom exceeding 4 inches in diameter. They contain numerous horizontal and vertical lines of weakness, seams, and cracks, and often break into more or less prismatic forms, with the vertical axis the longer. The ultimate prismatic unit, determined by picking the material apart until it no longer breaks along definite planes, seldom exceeds ½ inch in any dimension.

In many places throughout the area of Grundy soils columnar form is not developed in the zone of compaction. The material has no definite structure but breaks into hard, sharply angular clods of irregular sizes and shapes. Between the two extremes, prismatic and irregular, are found intermediate structural characteristics, but apparently the soil aggregates of this horizon are more angular and have sharper edges and corners than those of the granular zone.

The mass color of the zone of compaction is grayish brown to very dark grayish brown, averaging considerably lighter than that of the granular zone. Gray and brown are dominant. The material is never black. The color is not uniform throughout but is a mixture of grayish brown, very dark grayish brown, and black. The darker intrusions are most numerous in the upper portion of the zone where they extend in all directions along seams and cracks in the clay, follow root or worm holes and insect borings, and occur as a coating over many of the soil aggregates. They are sometimes sharply defined but more often blend with and discolor the surrounding soil to such a degree as to give the material a rather uniform, very dark grayish brown appearance. These intrusions become less pronounced with depth, making the lower part of the zone a dark grayish brown. Scattering rusty brown iron stains and soft iron concretions are usually encountered throughout the horizon.

The material near the top of the zone of compaction has a much lighter color on a smooth-cut face or when pulverized than on a broken surface, but the difference becomes less pronounced with depth.

The horizon as a whole has a dull appearance. A broken face, however, often presents numerous polished surfaces which stand out clearly in the dominantly dull matrix. The material attains a high polish on the soil auger.

The density of the zone of compaction varies considerably. It decreases rapidly near the western and northern boundaries of the Grundy area, where the soil grades into the Holdrege and Marshall types. The zone also becomes less dense in proximity to drainage ways. It is usually the first one in the profile to become altered where the Grundy soils merge with other series. This transitional condition around drainage ways occupies very narrow strips upon the slopes and adjacent flats. At the western and northern boundaries of the main area, however, it continues as a broad belt, 12 to 24 miles wide, in which the zone of compaction is neither as thick or dense as that of the average Grundy soil nor nearly as friable as the corresponding layer in the Holdrege and Marshall groups. For this reason it seems desirable either to establish a new series for this (Semi-Grundy) or to correlate it with some phase of the Grundy soil.

Heretofore in enumerating the variations in the zone of compaction, the description has been confined to the zone in which the gray and brown colors dominate, which, together with the transitional material along drainage ways, is thought to underlie the greater part of the Nebraska Grundy For convenience in reference, this zone will be called the "Brown Clay-pan Horizon," and its more friable associate, which is in reality transitional in density between Grundy and Marshall or Holdrege, the "Brown Soft-pan Horizon."

BLACK CLAY-PAN

Throughout the entire Grundy region of Nebraska, aside from the outlying bodies north of the Platte for which there are insufficient data, are areas in which the brown and gray colors of the zone of compaction give way to extremely dark grayish brown or dense black. Although the black horizon is known to occur quite generally throughout the Grundy region, its exact boundaries have not been determined. It exists over rather large areas in the central and eastern parts of the region and in places around the western and northern borders.

COMPARISON OF HORIZONS OF COMPACTION

The outstanding difference between the extremely dark zone of compaction and the brown clay-pan zone is color. This color difference in Nebraska is so pronounced and so persistent that areas in which the darker color occurs are tentatively called "black clay-pan" Grundy by the state and federal soil men.

The color of the black clay-pan horizon is usually quite solid, the upper part often being as dark or darker than the laminated or granular zones. The density of color decreases with depth and usually becomes very dark grayish brown near the bottom. When pulverized or examined on a smooth-cut face, the color is considerably lighter in the upper portion than that of a broken surface, but this difference is less pronounced in the lower part.

The material of the black zone of compaction, wherever examined, has been extremely and constantly dense. It averages slightly heavier in texture and more compact than that of the brown clay-pan horizon, but the difference in density and texture is probably not sufficient to warrant separation in soil mapping.

The brown and black clay-pans have about the same structural range There is some variation in topography, but to what extent this may be used in lieu of subsurface examination in actual soil mapping has not been determined. It seems, however, that the black clay-pan underlies an extremely level or slightly depressed topography more often than one characterized by even faint undulations. In the central part of the Grundy region the material is undoubtedly more abundant within the extensive shallow depressions or on the extremely level surfaces than upon the intervening slightly elevated areas, but it occurs on both forms of topography. Near the western and northern borders of the region, the black clay-pan occurs chiefly in the better drained parts of depressed areas the low portions of which are occupied by the poorly drained Scott soils.

No difference was observed between the black and brown clay-pan layers in the arrangement or habits of grassroots. The root systems, however, are less abundant and appear to have less spread or feeding range than in the more friable layers above. The larger or trunk members extend downward chiefly along seams, cracks, or joints in the clay, but the lateral roots and root hairs appear to penetrate the dense clay, for short distances at least, with little regard for lines of weakness.

Neither the brown nor black clay-pan zones of compaction contain sufficient lime for acid reaction.

LIME ZONE

This, the fifth horizon in the profile, is not persistent in the Grundy soil. It varies much in the content and distribution of the carbonates.

The lime may occur in any one of the following manners: (1) As a definite accumulation of soil lime below which effervescence with acid ceases; (2) as a definite accumulation below which the lime decreases noticeably but does not disappear to depths examined; and (3) as parent material lime, uniformly distributed to great depths throughout the underlying loess-like deposit. In addition to these three modes of distribution there are areas in which no noticeable effervescence occurs in the Grundy soils, to depths below 8 feet, or the minimum depth attained in the observations on lime distribution.

The areas characterized by one or another of the methods of lime distribution are known only in a general way. (See map) These studies indicate, however, that the method of occurrence is quite constant in the area characterized by the form of distribution first mentioned. This area has been studied more thoroughly than the others. It occupies the southeastern portion of the Grundy region and occurs as an irregular triangular shaped body tapering northward from the Nebraska-Kansas line. The boundary coincides with the eastern edge of the Grundy region for about 50 miles, then extends approximately 30 miles northwestward, thence southwestward, crossing the Kansas line south of Hardy, Nebraska. Within this large area occupied by about 50% of the Grundy soils of Nebraska, the zone of maximum compaction is underlain by one of lime accumulation, and this in turn by material too low in lime to effervesce visibly when acid is applied.

The lime zone in this large area is usually encountered at a depth of 3 or 4 feet, but may be slightly deeper near the borders of its range. It varies in thickness from 6 or 8 inches to about 4 feet. The maximum concentration seldom exceeds 18 inches and usually occurs near the top, immediately beneath the zone of maximum compaction.

Columnar form or breakage may extend into this horizon but is seldom well developed and in many of the profiles examined was not observed.

The material may be slightly compact in the upper portion of the zone where it has become more or less mixed with the heavy clay of the overlying layer, but throughout most of the horizon it is usually a loose, friable silt or silty clay.

The general or basic color is grayish brown or yellowish brown, similar to, or only slightly darker than unweathered loess. Scattering rusty brown iron stains and concretions are common.

Lime is abundant and may occur in several forms. It may be finely divided powder-like material thoroughly mixed with the silt. It may be concentrated along old root and root hair channels, insect and worm holes assuming in places a dendritic arrangement. It may occur as a thin white film in the small seams and cracks of the soil. It may be in the form of soft concretions, hard concretions or soft concretions with indurated centers. These forms seldom occur singly in the horizon but are usually combined or intermixed to a greater or less extent Concretionary forms usually dominate and the disseminated lime especially is sparce. In many places the entire lime content seems to be concentrated in the numerous concretions and no lime reaction is obtained in the soil. The concretions are subspherical in form with rough surface They vary from 1/20 to ¼ inch or more in diameter.

Hard concretions dominate Toward the western and northern borders of the area characterized by the method of lime distribution under discussion, however, the peripheries of the concretionary forms are more often coated with soft floury lime. This coating appears to increase in thickness at the expense of the indurated centers and the disseminated lime becomes more abundant as one nears the boundaries of the horizon's distribution.

Roots are not noticeably abundant in the lime zone. However, they have probably been numerous at one time or another as evidenced by the tortuous needle-like canals which thoroughly ramify the soil in many places.

The horizon sometimes contains a few "borings" or rounded and twisted rod-like intrusions about ¼ inch in diameter. These are slightly darker and denser than the remainder of the matrix. They are not a characteristic feature.

At the base of the zone of maximum carbonate accumulation the concretions become softer, smaller, and more scattered, entirely disappearing at 5 to 8 feet, and the soil material fails to give a visible acid reaction.

Iron stains and concretions are numerous below 7 or 8 feet. They vary in color from rusty brown to almost black, but the darker ones usually increase with depth. In a few places a thin layer of ferruginous material is encountered at varying depths beneath the zone of lime occurrence.

The material as a whole appears to contain more iron stains and concretions than the gray loess member which underlies the area, but this difference does not persist at all points.

The remaining methods of lime distribution in the Grundy soils of Nebraska have not been studied sufficiently to warrant more than a general statement regarding their locations. In general, the second method, or the one characterized by a zone of accumulation beneath which some lime continues, dominates that portion of the main Grundy body west of the area in which lime disappears. It roughly coincides with the area in which the "brown soft-pan horizon" of compaction prevails. The lime zone is usually lower than in the area previously described, notwithstanding the more westerly location and slightly lower rainfall. Its average depth is about 5 feet. It is rarely above 4 feet. The greater depth is accounted for, in part at least, by a rather thick transitional layer between the zones of maximum compaction and lime accumulation. The lime throughout this western area also occurs in softer forms than in the region farther east There are fewer hard concretions and disseminated lime is more abundant. Beneath the zone of maximum carbonate accumulation, lime decreases rather abruptly as determined by the degree of acid reaction, but scattering concretions and considerable disseminated lime continue with little variation to below 12 feet. This mode of lime distribution is not confined to the Grundy soils alone but is a characteristic feature in nearly all the mature soils throughout central and western Nebraska.

In and throughout a small area in the northern part of the main

Grundy body there is no zone of unusual carbonate concentration. The lime is much deeper than in the remainder of the Grundy soils. It is seldom encountered above 6 feet and often does not occur in sufficient quantities to react visibly with acid within 10 or 12 feet. There appears to be no uniformity in the depth of lime. It may occur near 6 feet in one place and, if present at all, lie below 12 feet a mile distant. Where encountered in these observations it was uniformly distributed as soft concretions and finely divided powder in the underlying loess.

Similar conditions in reference to lime distribution are thought to exist in the two Grundy areas north of the Platte River, but knowledge of these is confined to only three profile descriptions and does not warrant any definite conclusion. It is known, however, that a similar method of distribution is characteristic of nearly all the mature upland and terrace soils of eastern Nebraska, including those of the Marshall, Waukesha, and Carrington groups.

SUMMARY

Observations on the Grundy soils of Nebraska may be summarized as follows:

1. These soils occupy over 4,000 square miles, occurring chiefly in the southeastern and east central parts of the state where they occupy the more nearly level loess plains.
2. About 75% of the soils lie between 1,650 and 1,850 feet above sea level.
3. There is uniformity in climate, vegetation, and parent material throughout the area.
4. The upper three horizons of the profile are persistent in the area. They are a structureless mulch, a laminated horizon, and a granular zone, each of which is quite friable and remarkably uniform in structure and relative position but varies, within narrow limits, in color and texture and considerably in thickness.
5. The fourth horizon is the one of maximum compaction. It varies decidedly in color, density, and structure, but does not attain the friable condition existing in the corresponding layer of the Holdrege and Marshall soils. Varying combinations in color and consistency give rise to three well-defined variations. In one of these the color may range from grayish brown to very dark grayish brown, but the gray and brown shades dominate and the material is never black. It probably varies sufficiently in density to warrant a separation in soil mapping based on this feature alone. Where the material is extremely dense and clay-pan like it might, for instance, be correlated as brown clay-pan Grundy, and where it is decidedly less com-

pact but still remains too dense for Holdrege or Marshall it might be called brown soft-pan Grundy or correlated with a new series. The third variation differs from the brown clay-pan chiefly in its darker color, being very dark grayish brown to almost black. This color difference is thought to be sufficient to warrant recognition in the final correlation of the Grundy soils and the darker material might be classed as black clay-pan Grundy.

6. The fifth horizon is more variable than any above. It is characterized by differences in the content and distribution of lime. Throughout the southeastern part and including about 50% of the Grundy soils of Nebraska, there is a definite zone of lime accumulation beneath which carbonates disappear so far as could be determined in the field. In the western part of the Grundy region there is another area in which the profile contains a definite zone of lime accumulation. In this area, however, some lime continues to below 12 feet or the maximum depth of observation. In the northern part, and including the remainder of the main Grundy region, is a small area in which no zone of lime accumulation is developed. Any carbonates which may occur lie much deeper than in the other areas and are uniformly distributed throughout the underlying loessial deposit. In much of this section lime reaction does not occur within 10 or 12 feet of the surface.

7. In conclusion, it is advisable to mention that the information secured in these studies of the Grundy soils, and to a less extent those of the Marshall series, warrants some changes in the location of the line separating the lime of accumulation from that of the parent material in Nebraska. It is realized that any single line dividing these two methods of lime distribution will be more or less faulty, due to the presence of isolated bodies characterized by one mode of distribution and surrounded by another. Nevertheless, a general line of separation can be drawn on either side of which the mode of distribution will remain remarkably constant. From the information secured such a line would run about as shown on the map.

CERTAIN SOIL PROFILES IN SOUTHERN ILLINOIS[1]

E. A. NORTON AND R. S. SMITH[2]

Illinois presents a particularly favorable field for the study of soil formation, definition, and grouping. The character of the climatic environment in which the soils of Illinois were developed has been fundamentally similar throughout the state, yet soils in various stages of development occur. The weathering of several kinds of parent rock produced the present soil material. Five different glaciations are exposed, affording excellent opportunity to study weathering as affected by the time interval. The climatic conditions near the southern extremity of the state approach those of a warm, moist climate with mild winters and hot summers, while those of the northern part approach a cold climate with less rainfall and severe winters. A comprehensive discussion of the soils of the state would necessarily be lengthy, so this paper is limited to a discussion of the soils occurring in a particular part of southern Illinois. (See Fig. 1.)

This portion of the state lies mainly within an area bounded by the 38th and 39th degrees of latitude, and the 88th and 89th degrees of longitude. The topography of this area was originally an unusually level and flat plain, lying from 450 to 600 feet above sea level, and broken in only a few places by low preglacial ridges and drift knolls. Drainage has dissected the southern half until the divides are comparatively narrow and the valleys broad, while in the northern half the divides remain broad and flat and the valleys narrow The mean temperature in this area for the past 60 years has been 55°F; the average rainfall, 41.5 inches; and the average growing season, 188 days. The ground is seldom frozen for more than six weeks throughout the year, so that the process of leaching has been almost continuous and the soil is locked up by frost only a few weeks each year. Forest vegetation, consisting chiefly of oak, hickory, elm, and ash, has followed the advance of drainage and overspread most of the upland in the southern half, but is confined to narrow belts along the drainage channels in the northern half leaving many broad, flat prairies. A fair growth of grasses covered the prairie region prior to the advent of man. The failure of a forest vegetation to cover this

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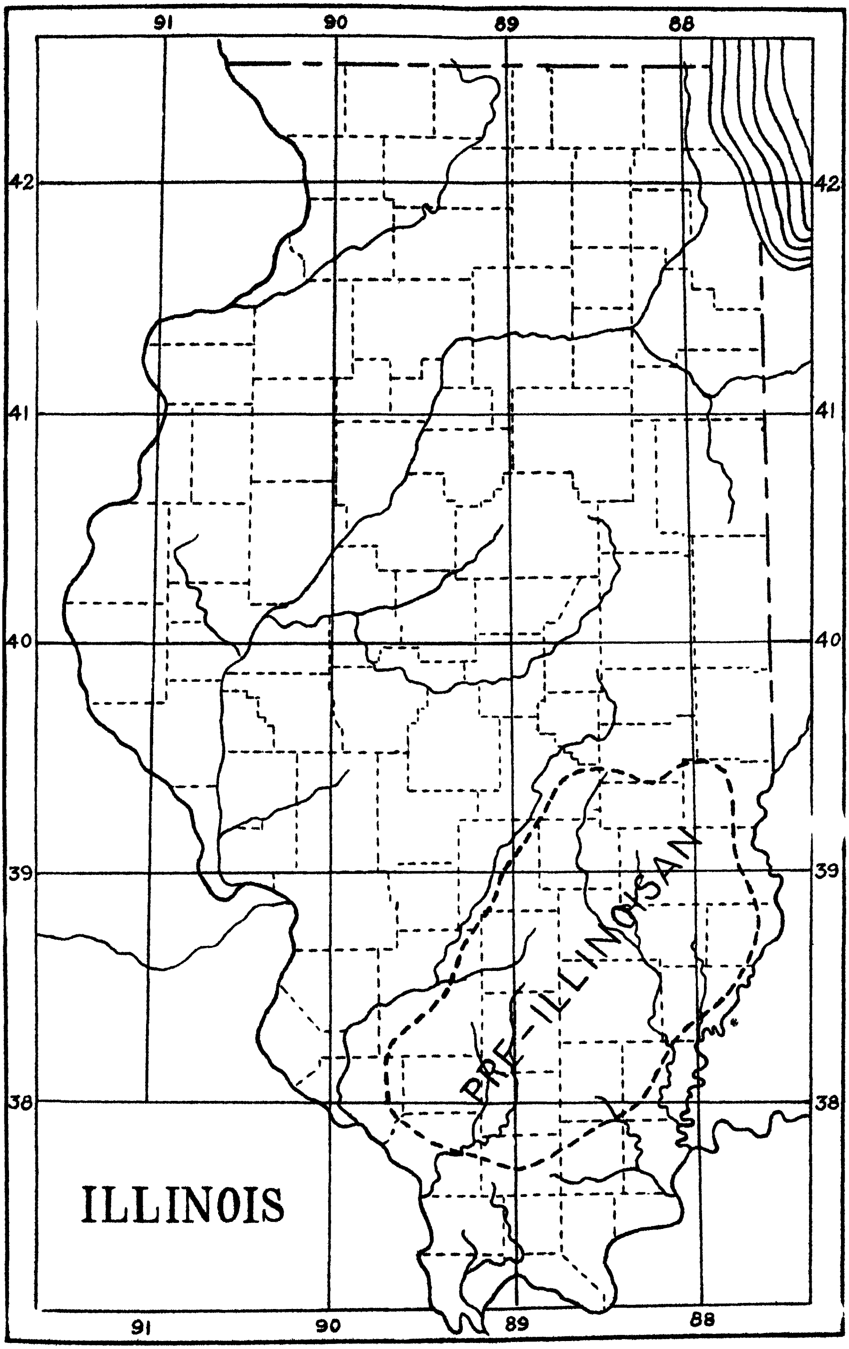

FIG. 1.—Area of Pre-Illinoisan glaciation exposed in southern Illinois.

area where climatic conditions are favorable for its growth may have been due to accidental causes, such as fires continually burning the new growth, or to the fact that very poor drainage is more conducive to prairie than to forest vegetation.

A Pre-Illinoisan ice invasion furnished the parent material from which the present soils were formed. Some sorting of the weathered surface material was undoubtedly made by the wind, but evidence does not substantiate the belief that any great amount of loess was deposited even though few drift pebbles can be found in the 30-inch section The soil material is described as being loess-like and is probably derived almost wholly from thoroughly weathered glacial drift. The deposit of drift from this ice invasion varies in depth from a few feet to more than 100, and averages about 25 feet over the entire area. The drift has been leached of its carbonate to a depth of about 14 feet in the southern part and to a depth of 11 feet in the northern part This difference may be due to a difference in the original lime content of the drift, that is, less lime in the drift which lies farther from the source of calcareous rock, or to the more pronounced effect of the weathering forces in the southern part.

The soils of the area can be readily classified into two main groups on the basis of color of the surface soil, namely, (1) gray and (2) yellow, or soils with a yellow cast The influence of vegetative cover, which has been the dominant factor in determining the color of the surface soil in this region, has been greatly reduced by extensive weathering. Because of this fact, a description of one of the above-mentioned soil groups and a comparative statement showing the relationship between the groups will be sufficient to acquaint one with the soils of the region, since corresponding types exist in each group. The presence of a plastic, compact, weathered drift, known as gumbotil, which is found in all the flatter parts of the area, suggests that drainage was one of the most important environmental factors in the formation of the soil The profile of gumbotil which will be described later is very similar to that of the upper soil profile. The presence of the characteristic gumbotil profile on all the flat regions of this area and its absence on the rolling areas suggests that the soils may be further divided into two groups, those formed on flat topography under conditions of poor drainage and those formed on rolling topography with good drainage.

In the following detailed profile descriptions of the yellowish colored surface soils, those formed under conditions of poor drainage are given first followed by those formed under good drainage conditions. In order to eliminate lengthy descriptive names, the types are indicated by numbers. The designation of horizons as used in these descriptions is explained as follows· A includes the horizons above the zone of accumulation, B includes the horizons of maximum accumulation, and C refers to the friable weathered material below the zone of accumulation and above the unleached parent material The degree of weathering is not the criterion used in determining the C horizon.

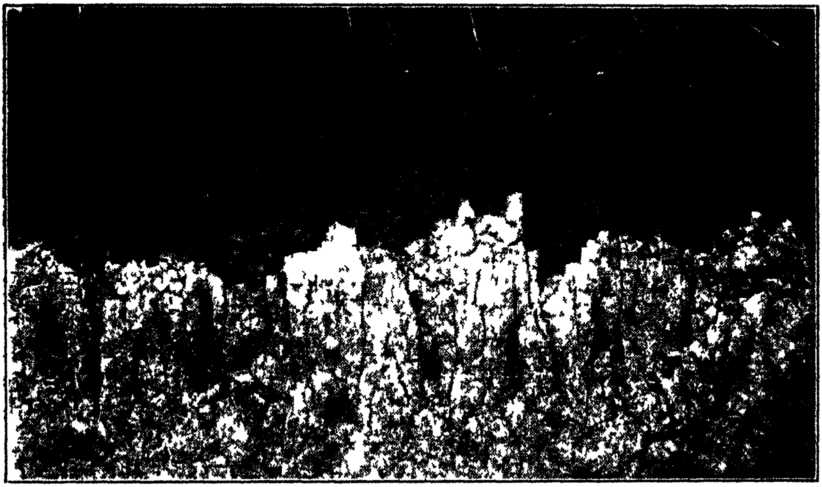

FIG. 2 Columnar form, typical of the B horizon of all mature soils developed under conditions of poor drainage in southern Illinois

TYPE NO 11

This profile has developed on areas where the slope is less than 0.3% and under conditions of very poor drainage The description applies to virgin timber areas.

A_1—0 to 4 inches—pale yellowish gray silt loam, laminated, friable, containing brownish black iron pellets; a very thin forest litter covers the surface.

A_2—4 to 16 inches—light gray silt loam, friable, heavily splotched with reddish brown iron.

A_3—16 to 24 inches—very light gray, silty clay loam, ashy, mostly friable, heavily splotched with brown iron; columnar form begins to appear in this horizon. (See Fig 2.)

B_1—24 to 32 inches—light drabbish gray clay, very plastic and compact, columnar, splotched with reddish brown iron; breakage is in large angular blocky particles which are gray coated.

B_2—32 to 40 inches—gray clay, very plastic and compact, columnar, splotched with reddish brown and black iron; horizontal surface of particles coated with drabbish gray, vertical with light gray.

B_3—40 to 72 inches—light gray sandy clay, medium compact and plastic, columnar, heavily splotched with brownish black iron; the angular blocky particles have their vertical surfaces covered with very light gray material.

B_4—72 to 81 inches—grayish drab, sandy, gravelly clay, very plastic and compact; columns continue through from horizon above.

B_5—81 to 98 inches—gray, sandy, gravelly clay, plastic and compact, columnar form not so prominent.

B_6—98 to 103 inches—yellowish brown accumulative iron zone, compact.

C—103 inches to parent material—weathered yellow drift, sandy, gravelly.

11 to 14 feet—calcareous drift, parent material.

Fibrous roots fill the A horizon, while but few enter B. The roots in B occur in cracks between particles. Old root channels are filled with light gray material. Animal burrows and casts are not abundant and are usually confined to the A horizon. The lower portion of this profile from 72 to 103 inches has been termed gumbotil by glacial geologists and is supposed to have developed under conditions of very poor drainage. The upper portion of the profile, above 40 inches, has developed since a change in the original drainage occurred and might be termed a super-imposed profile. As drainage conditions improved, the horizons in the portion of the profile above 40 inches became more distinct and a somewhat friable zone developed between the upper portion of the profile and the gumbotil. The light gray color and the thickness, plasticity, and compaction of the B horizon in this profile illustrate the predominant characteristics of soils matured under poor drainage in this area.

TYPE NO. 12

This profile has developed on slopes varying from 0.3 to 1.2% under conditions of drainage which, though poor, are better than those under which type No. 11 was developed. This description applies to virgin timber areas.

A_1—0 to 5 inches—yellowish gray silt loam, laminated, friable, containing brownish black iron pellets; very little forest litter accumulates on the surface.

A_2—5 to 17 inches—pale yellowish gray silt loam, friable, containing numerous black iron pellets.

A_3—17 to 20 inches—light gray, silty clay loam, ashy, friable, containing numerous black iron pellets; columnar form appears in this horizon.

B_1—20 to 28 inches—brownish yellow clay, gray coating the large angular blocky aggregates, very compact and plastic, columnar, splotched with reddish brown iron.

B_2—28 to 34 inches—yellowish gray clay, very compact and plastic, columnar, heavily splotched with reddish brown and black iron; the vertical faces of the large angular blocky aggregates are covered with gray, horizontal faces covered with brownish yellow.

B_3—34 to 46 inches—pale yellowish gray, sandy clay, compact, non-plastic, heavily splotched with yellowish brown and black iron; columns have almost disappeared.

B_4—Same as B_3 of type No. 11. The profile is very similar to No. 11 below this point.

Many fibrous roots occur in the A horizon and very few in the deeper horizons. The roots follow cracks in the B horizon. Old root channels are lined with a light gray friable material and in lower B they are filled with a more plastic material. Animal burrows and casts are not abundant in this type and are usually confined to the A horizon. The outstanding characteristics of a profile formed under very poor drainage conditions are exhibited by this profile, but they are not so well developed as in No. 11. The upper section of the profile is distinctly separated from the lower by the B_3 horizon.

TYPE NO. 13

Type No. 13 has developed on slopes varying from 1.2 to 3 5%, and under conditions of fair drainage. The characteristics of this type show that its profile is intermediate in development between those formed under conditions of poor drainage and those of good drainage This description applies to virgin timber areas.

A_1—0 to 6 inches—grayish yellow silt loam, laminated, friable, forest litter about 1 inch in thickness.

A_2—6 to 14 inches—yellow silt loam, friable, spotted with reddish yellow.

A_3—14 to 17 inches—pale reddish yellow silty clay loam, heavily streaked with gray in both lateral and vertical cracks, slightly compact, non-plastic; slight evidence of columnar form.

B_1—17 to 23 inches—reddish yellow clay loam, large angular blocky aggregates break in all directions and are vertically coated with a heavy gray layer, horizontally with a yellowish brown, medium compact and plastic, showing a faintly developed columnar form.

B_2—23 to 28 inches—reddish yellow clay loam, large angular aggregates coated with reddish brown, medium compact and plastic; columns faintly discernible, but lose their identity near the bottom of this horizon.

C_1—28 to 36 inches—reddish yellow silty clay loam, aggregates smaller than in B and thinly coated with reddish brown and splotched with yellowish brown iron.

C_2—36 inches to parent material—yellow silty clay loam, friable, sandy, gravelly, streaked with gray.

The above profile occurs imposed upon a previously formed profile on areas where drainage has recently changed for the better. The stage of development is related to the duration of time since the change in drainage occurred. Animal burrows have mixed the horizons in this type, chiefly the A and B. Animal casts have a gray coating, especially if found in B or C. Roots are well distributed throughout the profile and seem to pierce the aggregates as easily as they advance in the cracks. Old root channels in the B and C horizons become filled with a material which is more plastic than the surrounding mass. The faces of the aggregates are stained with dark brown organic matter which is surrounded by a thin gray film.

TYPES NOS. 14 AND 15

The following two profiles were formed under conditions of good drainage. Their occurrence is limited in this area. Type No. 14 has developed on slopes varying from 3.5 to 7%. The description applies to virgin timber areas.

A_1—0 to 5 inches—yellowish brown silt loam, friable, covered with about 1 inch of forest litter.
A_2—5 to 9 inches -brownish yellow silt loam, laminated, friable.
A_3—9 to 15 inches—reddish yellow silt loam, friable.
B—15 to 24 inches—reddish yellow clay loam, small angular aggregates coated with reddish brown, slightly compact non-plastic, aggregates break easily in all directions.
C_1—24 to 30 inches—pale reddish yellow silt loam, streaked with gray which is probably contained in old root channels, friable.
C_2—30 inches to parent material—reddish yellow, sandy silt loam, small angular aggregates coated with reddish brown and occasionally streaked with gray which probably follows old root channels, very friable.

Roots are well distributed through this profile. They stain the soil a dark brown and the old channels contain a grayish material which is more compact than the surrounding mass. Animal burrows mix the horizons, usually carrying material from below to those above. The old holes in horizons B and C are filled with material which is darker than the surrounding mass.

The area of type No. 15 in this region is very limited. It has developed on slopes varying from 7 to 14%. The description applies to virgin timber areas.

A_1—0 to 4 inches—yellowish brown silt loam, friable, containing little forest litter.
A_2—4 to 10 inches—reddish yellow silt loam, friable, with faint traces of lamination.
B—10 to 20 inches—reddish yellow silt loam, streaked with reddish brown, slightly compacted but friable; aggregates are small and angular, breaking easily in all directions.
C—20 inches to parent material—reddish yellow sandy silt loam streaked with reddish brown, very friable; drainage lines have a faint gray cast.

The roots are well distributed throughout this profile, and as they decay leave a distinct brownish black stain on the surrounding soil. Slopes of more than 14% erode too rapidly for a profile to form.

The corresponding types in the gray-colored surface soil group differ from the above mainly in the color and depth of the A_1 horizon and in the presence of a distinct orange or red iron mottling in the A_3 and B_1 horizons of the types corresponding to Nos. 13 and 14. Naturally, the prairie grasses would furnish more organic matter than the forests, so that the A_1 horizon in the prairie types would be thicker and darker than the corresponding horizon in the timber types. The reason for the existence of the distinct red coloring in A_3 and B_1 is not well understood, but undoubtedly is connected with the chemical state in which the iron is held. The B_1 horizon of the gray-colored surface soil group is often slightly darker in color than its corresponding yellow-colored surface soil type, owing to the higher organic-matter content in the A_1 horizon.

THE "SLICK SPOT" TYPE

Another soil type frequently occurs in this area which seemingly has no relation to any of the above-described profiles. It has been called the "slick spot," and little is known about it except that alkaline salts have accumulated in the upper soil profile, that the A horizon is very shallow, and that the B horizon is very thick. Its past drainage history has undoubtedly been different from that normal to the region.

DISCUSSION

These profiles illustrate the fact that a good correlation exists between topography and drainage and important soil characters. For example, as the slope and drainage increase, compaction decreases, as do also plasticity; the thickness of the ashy gray layer, A_3; the depth to the B horizon, the thickness of this horizon, and the depth to the C horizon; lime requirement as given in terms of pH; and the gray color in the profile. Oxidation and color increase as the slope and drainage increase.

Cultivation of the soils in this area has lightened the color of the surface by mixing some of the lighter colored A_2 with the A_1 horizon. It has increased the lime requirement and intensified the plasticity and compaction in the B horizon. The prosperity of the region averages low. The relative productivity of types 11, 12, 13, and 14 with reference to wheat may be approximated by the following proportion: $11:12:13:14 = 1:2:3:2\frac{1}{2}$.

The profiles in this area indicate that the resultant product of the soil-forming forces in a humid temperate climate will be a light-colored soil with a thick A and a thick, plastic, and compact B horizon when formed under conditions of poor drainage, and a yellow-colored A and a thin and friable B horizon when formed under conditions of good drainage.

BUFFER CAPACITY OF SOILS AND ITS RELATION TO THE DEVELOPMENT OF SOIL ACIDITY FROM THE USE OF AMMONIUM SULFATE[1]

W. H. Pierre[2]

That property of the soil which enables it to resist a change in its H-ion concentration by the addition of an acid or base has been variously referred to as buffer effect, buffer action, or buffer capacity. Although these terms have been used synonomously it would help materially to clarify discussions if the term "buffer action" were used to denote the general property of buffering by soils, and the term "buffer capacity" to indicate the numerical value of this property. These terms will be used in this sense in this paper.

Many nvestigations of the lime requirment of soils have treated more or less indirectly with the buffer action of soils toward base. As far as the writer knows, however, no work has been done on the buffer action of soils toward acids with the purpose of determining the rapidity at which different soils develop an injurious acidity when fertilized with physiologically acid fertilizers. In view of the large increase in the production of such physiologically acid nitrogen fertilizers as ammonium sulfate, ammonium nitrate, urea, and ammonium phosphate, it seems of decided importance to have a method for estimating the residual acidic effects of such fertilizers on different soils.

That ammonium sulfate causes soils to become acid has long been an established fact. The long-time experiments at the Rothamsted, Pennsylvania, Ohio, Rhode Island, Massachusetts, and New Jersey experiment stations have proved that after a period of years the unlimed ammonium sulfate plats produced much smaller yields than the plats fertilized with sodium nitrate, and that the decreased yield was accompanied by an increased acidity of the soil. In most of these fields, however, the injurious effect of ammonium sulfate was not evident until several years after the beginning of the experiment. Moreover, in comparing the value of various nitrogenous fertilizers in short-time experiments, much work has been reported showing that sodium nitrate and ammonium sulfate give practically the same yields. These results have caused a more or less general belief that the amount of acidity developed is small and that crops are injured only after repeated applications of ammonium sulfate. Most of the long-time experiments, however, have been conducted on heavy soils of presumably high buffer capacity. When one considers the large areas of sandy soils in the United States, especially in the southern states where a large proportion of the fertilizers of the country is used, a different situation obtains. Sandy soils possess low buffer capacities, and thus from a theoretical consideration should be injured in a relatively short period of time from the use of such physiologically acid fertilizers as ammonium sulfate. That this is true has been shown by the results of a field experiment conducted at the Alabama Experiment Station on a sandy soil, comparing different sources of nitrogen. The question, therefore, as to how quickly different soils will become injured by the use of physiologically acid fertilizers is of considerable practical importance.

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[1] Contribution from the Soils Laboratory, Department of Agronomy, Alabama Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication January 22, 1927.

[2] Associate Soil Chemist.

In order to study this problem, this investigation was started with the following objects in view: (A) To develop a simple and accurate laboartory method for determining the buffer capacity of soils, (B) to study by means of the laboratory method the buffer capacity of a number of soils from Alabama and other states, and (C) to determine whether or not the buffer capacity of soils as determined by the laboratory method gives an accurate index of the rapidity with which ammonium sulfate fertilization causes soils to develop an injurious acidity.[3]

METHODS OF DETERMINING BUFFER CAPACITY

The various methods that have been used to determine the buffer capacity of soils are much the same in principle. They consist, essentially, in adding to the soil a definite amount of a dilute solution of acid or base and in determining the resulting H-ion concentration after equilibrium has been established. The methods used by the various investigators differ mainly in the kind of acid or base used, the procedure employed in obtaining equilibrium, and the method of determining the resulting H-ion concentration.

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[3] While ammonium sulfate has been used in these studies because of its more general use, it must be remembered that the other physiologically acid nitrogen fertilizers mentioned have an acidifying effect which differs only in degree from that of ammonium sulfate.

The method of Arrhenius (1)[4], the first investigator to report much work on buffer capacity, was as follows: To a series of flasks was introduced 5 grams of soils, varying amounts of 0.1 N H_2SO or HCl, and distilled water to make the solution in each flask to 20 cc. The flasks were then stoppered, shaken for a time, and allowed to stand. After 24 hours, the suspensions were filtered and the pH values determined colorimetrically on the extracts.

Charlton (2) used a very similar method, except that he obtained equilibrium by shaking his flasks continuously for a period of 24 hours at 30°C, and that he obtained his extracts by the centrifugal method.

Runk (4) used a 1 to 10 dilution of soil to water and titrated his suspension electrometrically by adding 0.01 N H_2SO_4 or NaOH directly into the electrode vessel.

In all the above methods, equilbrium was obtained at ordinary temperatures. Stephenson (5), however, used a method whereby the mixture of soil, acid, and water was first evaporated to dryness on a steam bath. The residue was then taken up in water and the H-ion determination made electrometrically on the suspension after allowing it to stand over night. The chief objection to this method is that heating soils at the temperatures obtained may result in a different point of equilibrium being established than is established at ordinary temperatures. The writer found from a brief study of the method that some soils may change their reaction 0.3 pH as a result of this heating treatment.

It would seem from a brief consideration of these methods that those employed by Arrhenius and Charlton are the most simple and the best adapted to routine analytical work. These investigators allowed the reaction to go on at ordinary temperatures and used the colorimetric method of determining the H-ion concentration. The method used by Runk may give the same results provided enough time is allowed for equilibrium to become established, but it is decidedly more tedious where a number of determinations are to be made.

PROPOSED METHOD

In a recent paper (3) from this laboratory, the value of collodion sacks for obtaining clear soil extracts was shown. Emphasis was given to their value in making H-ion determinations by the colorimetric method, and mention was made of their use in determining buffer capacity of soils. The method therein briefly described will be given here in more detail, as follows:

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[4] Reference by number is to "Literature Cited," p. 351.

In a series of 150-cc extraction flasks are placed collodion sacks of size and shape similar to the flasks themselves. Twenty grams of the soil, the buffer capacity of which is to be determined, are then poured into each sack by means of a powder funnel. One flask is left untreated, whereas various amounts of 0.1 N H_2SO_4 or 0.1 N $Ba(OH)_2$, as the case may be, are added to the other sacks. Distilled water is then added, partly to the inside and partly to the outside of the sacks, to make the total volume of solution to 100 cc. The necks of the sacks are then folded against the necks of the flasks, clean rubber stoppers are inserted, and the flasks shaken five or six times by hand during the next 24 hours. H-ion determinations are then made colorimetrically on 5 cc of the dialysate withdrawn from outside of the sacks. While equilibrium is usually attained in a period of 24 hours, as will be shown later in this paper, the flasks are set aside for another 24 hours, given the usual shaking, and the pH values again determined. If the H-ion concentration has not changed more than 0.05 pH, the readings of the first day are considered at equilibrium, and from these values the buffer capacity of the soil is calculated.

The advantages of this method over those of Arrhenius and Charlton are as follows: (A) A clear extract is always secured, (B) it is much more rapid where a number of determinations are to be made, and (C) it makes it possible to determine whether or not equilibrium has been obtained by making determinations after various periods of contact without necessitating a second filtering or centrifuging of the suspension.

USE OF DIFFERENT ACIDS AND THEIR EFFECT ON THE TIME NECESSARY FOR EQUILIBRIUM

Since the different investigators have used different acids, it seemed important to know whether or not the kind of acid used might influence the equilibrium obtained. Arrhenius (1) compared the effects of hydrochloric, sulfuric, nitric, and acetic acids and concluded that the same equilibrium values are obtained when equivalent amounts of the strong mineral acids are used. His comparisons, however, were made on only one soil and only in the pH range 7.0 to 5.7. It seemed important, therefore, to study this question in more detail. Moreover, it was thought advisable to study at the same time the possible effect of the different acids on the period of time required for equilibrium.

Four soils varying widely in texture, organic matter content, and buffer capacity were used for this study. The different acids were added in equivalent amounts. The flasks were all set up at the same time and received the same amount of shaking. The H-ion determinations were made at the end of 24, 48, and 72 hours. The results are given in Table 1.

TABLE 1.—*The H-ion concentration of soils after contact with equivalent amounts of different acids for various periods of time.*

Soil type	cc. of 0.1 N acid to 20 grams of soil	HCL			H_2SO_4			HNO_3		
		Period of contact			Period of contact			Period of contact		
		24 hours	48 hours	72 hours	24 hours	48 hours	72 hours	24 hours	48 hours	72 hours
	0	6.15	6.20	6.20	6.15	6.20	6.20	6.15	6.20	6.20
Lintonia silt loam	1.2	5.05	5.40	5.60	5.60	5.60	5.75	5.40	5.40	5.60
	2.0	4.80	5.00	5.00	5.00	5.05	5.05	5.00	5.05	5.05
	2.8	4.50	4.60	4.65	4.80	4.80	4.85	4.70	4.75	4.80
	0	5.85	5.85	5.95	5.85	5.85	5.95	5.85	5.85	5.95
DeKalb fine sandy loam	0.4	5.45	5.60	5.65	5.55	5.60	5.60	5.35	5.45	5.50
	0.8	4.85	5.00	5.05	5.05	5.05	5.05	4.95	5.00	5.00
	1.2	4.60	4.65	4.80	4.80	4.80	4.85	4.75	4.80	4.85
Hempstead silt loam	0	5.35	5.40	5.45	5.35	5.40	5.45	5.35	5.40	5.45
	1.6	4.75	4.80	4.80	4.80	4.80	4.80	4.70	4.70	4.75
	3.6	4.35	4.40	4.40	4.40	4.40	4.45	4.40	4.40	4.45
Norfolk sand	0	5.65	5.65	5.65	5.65	5.65	5.65	5.65	5.65	5.65
	0.4	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
	0.8	4.50	4.55	4.60	4.55	4.60	4.60	4.50	4.55	4.55

It will be seen from the data obtained that the different acids give about the same point of equilibrium provided the reaction is allowed to continue for 72 hours. The time necessary for equilibrium to become established, however, varied considerably with the different acids. With sulfuric acid there was little change in the H-ion concentration between 24 and 72 hours, but with nitric and hydrochloric acids a gradual change occurred in many cases.

It is evident, therefore, that the use of sulfuric acid is to be preferred, and that with its use the buffer capacity of a soil toward acid can for most purposes be determined in 24 hours. There were a few soils of the large number studied with sulfuric acid, however, where changes greater than 0.05 pH occurred between 24 and 48 hours. Therefore, where small differences in the buffer capacity of soils are to be determined, as in the following studies, it is preferable to make a second determination of H-ion concentration after 48 hours as recommended in the procedure described.

METHODS OF EXPRESSING BUFFER CAPACITY OF SOILS

In most of the studies reported on the buffer action of soils the results have been expressed as titration curves obtained by plotting the amount of acid or base used against the pH value. The slope of the curves indicates the degree of buffering by the soils. It is obvious, however, that whereas this method of making comparisons is quite satisfactory to show the buffer action of soils through the whole range of reaction, it is not suitable for making direct comparisons of a large number of soils.

The other method that has been used is that proposed by Charlton (2). By means of simple formulas he derived numerical values to express buffer capacity. A brief description will be given of his method since it is essentially the same as is used for recording the data in this study.

Charlton differentiates between the buffer capacity of soils toward acid and toward base. He describes total buffer capacity of soils toward acid as the number of cubic centimeters of N H_2SO_4 necessary to bring 100 grams of soil to pH 4.5. Similarly, the total buffer capacity of soils toward base is defined as the number of cubic centimeters of N $Ba(OH)_2$ necessary to bring 100 grams of soil to pH 9.5. Since, however, the original pH values. of soils vary, total buffer capacity values do not indicate the relative power of different soils to buffer a certain amount of acid or base. Therefore, Charlton gives two other expressions which he designates as the "buffer action per 1.0 pH" toward acid and toward base. Thus, the buffer capacity of soils toward acid per 1.0 pH is defined as the total buffer capacity divided by $X - 4.5$, where X represents the original pH of the soil. Similarly, the buffer capacity toward base per 1.0 pH is the total buffer capacity toward base divided by $9.5 - X$. It is evident that these four values are readily calculated and that they give a very concise and uniform method of designating buffer action and comparing the buffer capacity of soils.

This method of recording buffer capacity has been used, with minor modifications, in the following studies. Instead of using pH 4.5, however, as the lower limit to which the values were calculated. the value pH 4.8 was used. Since most of the common agricultural plants are definitely injured when a soil reaches pH 4.8 and since there is no special advantage of using 4.5, the former value is to be preferred. When, for purposes of study, other values are used in the following pages, the pH at which the calculations were made will be indicated.

Moreover, in order to simplify the terminology the writer proposes that the term "buffer capacity per 1.0 pH" be designated as "specific buffer capacity." Thus we would have the specific buffer capacity of soils toward acid and base as distinguished from the total buffer capacity toward acid and base, which may be explained for the acid phase by the following formulas:

1. Total buffer capacity toward acid[5] = cc of N H_2SO_4 per 100 grams of soil to change soil to pH 4.8.

2. Specific buffer capacity toward acid = $\frac{\text{Total buffer capacity toward acid}}{X - 4.8}$, where X is the original pH value of the soil.[6]

BUFFER CAPACITY OF SOILS TOWARD ACIDITY

Although considerable data have been reported by Arrhenius (1) and Charlton (2) on the buffer action toward acid of a number of foreign soils, little work has been done on the problem in this country. Arrhenius included in his study several soils from California, and Runk (4) reported work on a few soils from Delaware. Stephenson (5) has also reported work on a few Iowa soils, but since his method was very different from those used by other investigators, it is difficult to compare directly his results with the other reported data. It seemed desirable, therefore, to make a study of the buffer capacity of a number of soils from Alabama and from other sections of the country.

Table 2 gives the buffer capacity of a number of soils as determined by the laboratory method previously described. For the sake of comparison, some of the data reported by Arrhenius and Charlton are included. Since Arrhenius did not report his results according to the method herein described, it was necessary to make graphs from his data and from these make the necessary calculations. The buffer capacities of the soils reported by Charlton are given as calculated by him to pH 4.5 and, therefore, are not strictly comparable. The Alabama soils included in the table represent some of the coarser textured and the poorest soils of the state, such as No. 658, and some of the best clay soils, as for example No. 379. Those from other states represent soils of various types varying in texture from sandy loam to clays.

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[5] The use of normal acid and 100 grams of soil as the basis for calculation gives a numerical value which is equivalent to the milligram equivalents of hydrogen required to bring the soil to pH 4.8. In replaceable base studies the unit of measurement is milligram equivalents, and since recent studies at this laboratory indicate that there is a close correlation between the buffer capacity of a soil and its content of replaceable base, it seems desirable to be able to express buffer capacity in terms of milligram equivalents.

[6] Specific buffer capacity as defined gives values for different soils that are strictly comparable only when soils of approximately the same pH values are compared. This is because of the fact that the buffer action of a soil may vary at different ranges of the pH scale and because the pH scale is logarithmic instead of absolute. Therefore, in e amining the data of Table 2 this fact must be kept in mind. It will be seen that the specific buffer capacity data reported in the rest of the paper are of soils of the same or approximately the same pH values.

TABLE 2.—*The buffer capacity of soils.*

Lab. No.	Soil	Location	H-ion concentration of untreated soil	Buffer capacity to pH 4.8 Specific	Total	Investigator
372	Norfolk sand	Alabama	5.65	0.35	0.30	Author
373	Ruston sandy loam	Alabama	5.40	0.32	0.19	Author
374	Orangeburg sandy loam	Alabama	5.75	0.42	0.40	Author
375	Greenville sandy loam	Alabama	5.75	0.59	0.56	Author
379	Cecil clay loam	Alabama	5.85	1.27	1.33	Author
386	Decatur silt loam	Alabama	5.95	1.39	1.60	Author
387	DeKalb fine sandy loam	Alabama	5.85	0.60	0.63	Author
658	Norfolk sand	Alabama	5.50	0.21	0.15	Author
504	Cecil sandy loam	South Car'lina	5.90	1.45	1.60	Author
420	Tifton sandy loam	Georgia	5.80	0.94	0.94	Author
419	Brown silt loam	Mississippi	6.15	1.19	1.61	Author
557	Lintonia silt loam	Arkansas	6.20	1.00	1.40	Author
449	Hempstead silt loam	Minnesota	5.35	1.45	0.80	Author
562	Colby silt loam	Wisconsin	5.60	1.60	1.28	Author
319	Black clay loam	Illinois	5.40	3.13	1.88	Author
467	Hagerstown silt loam	Pennsylvania	5.60	1.50	1.20	Author
316	Saginaw clay	Michigan	6.60	3.11	5.60	Author
	Songei Mentjirim Black	Sumatra	7.00	1.83	4.03	Arrhenius
	Toentongan Black	Sumatra	7.00	6.91	15.20	Arrhenius
	Volcanic ash Kediri	Java	7.00	0.77	1.70	Arrhenius
	Soere Demak	Java	7.00	6.18	13.60	Arrhenius
	Sand El-Munayer	Egypt	7.00	0.91	2.50	Arrhenius
3A	Yolo silty clay loam	California	7.00	3.64	8.00	Arrhenius
6A	Yolo silty clay loam	California	7.00	5.32	11.70	Arrhenius
7A	Hanford fine sandy loam	California	6.70	1.95	3.70	Arrhenius
4	Palan	Burma	5.75	0.92	1.15	Charlton
5	Tatkon	Burma	6.90	1.77	4.25	Charlton
10	Kungyaunywa	Burma	6.10	3.13	5.00	Charlton

If the buffer capacities of the soils of this country are first considered, it will be seen that there are extreme variations. Thus, the specific buffer capacity varies from 0.21 for a Norfolk sand to 3.11 for Saginaw clay. This means that the latter soil is 15 times as strongly buffered as the former, or in other words, that it would require 15 times as much acid to change its reaction through a range of 1.0 pH. The differences in the total buffer capacity of these soils is still greater. The reason for this is obvious, for the original reactions of the soils are different. Another comparison which brings this point out is given by soils No. 419 and No. 449. The specific buffer capacity of No. 419 is lower than that of No. 449, and still the total buffer capacity of the former is twice that of the latter. Thus, it is evident that there are wide variations in both the specific buffer capacity and total buffer capacity of soils, and that both values must be considered in comparing different soils.

An examination of the buffer capacity of the soils reported by Arrhenius and by Charlton shows that these investigators also obtained wide variations. The values for the three soils taken from Charlton's work represent the maximum variations secured in his study of 13 soils from India. As will be seen, these values are comparable to those obtained by the writer. Arrhenius, however, reports soils of much higher buffer capacity. Thus, the value for a Yolo silty clay loam from California is nearly twice as high as the highest value for total buffer capacity reported by the writer. Two soils from Java and Sumatra give even higher values.

It is evident, therefore, that soils vary widely in their buffer capacity. In a consideration of the effect of the continued use of physiologically acid fertilizers on different soils, this fact would seem of considerable importance and will be discussed in more detail later.

BUFFER CAPACITY AS AN INDEX OF RAPIDITY WITH WHICH AMMONIUM SULFATE CAUSES SOILS TO BECOME ACID

Since different soils have marked differences in their buffer capacity toward acid, it seems logical that they should also vary in their ability to buffer the acid residues of such physiologically acid fertilizers as ammonium sulfate. The question then arises as to whether or not it is possible to determine accurately the rate at which ammonium sulfate will cause different soils to become acid by simply studying the buffer capacity of the soils in the laboratory. In order to study this problem, greenhouse experiments were first undertaken.

GREENHOUSE EXPERIMENTS

Ten soils from different sections of Alabama and four soils from other states, varying from coarse sands to clay loams, were used in this study. Ten 2-gallon pots were filled with each soil and fertilized in duplicate as follows: All pots except the two check pots received acid phosphate and muriate of potash at a rate of 1,000 and 100 pounds per acre, respectively. In addition, duplicate pots received ammonium sulfate at the various rates of 500, 1,000, and 2,000 pounds. Since the amount of fertilizer to be added to each pot was calculated on the basis of 10,000 grams of soil per pot for sake of convenience and since it was not always possible to get this amount of soil in the pots, the rate of fertilization varied slightly with the different soils. The first nine soils reported in Table 3 were cropped to oats, whereas the last five soils were grown to corn. After harvesting the crops, the soil in each pot was thoroughly mixed and sampled. H-ion determinations were then made on all samples by the dialysis-colorimetric method (3).

The results are reported in Table 3. Since with some soils the rate of ammonium sulfate fertilization was slightly more or less than the indicated 500 and 1,000 pounds per acre 2,000,000 pounds, graphs were made of the data and the pH values in Table 3 obtained by interpolation.

TABLE 3.—*The H-ion concentration of soils as affected by the use of different amounts of $(NH_4)_2SO_4$ fertilizer.*

Lab. No.	Soil type	Reaction of soil		
		Untreated pH	500 pounds $(NH_4)_2SO_4$ per acre pH	1,000 pounds $(NH_4)_2SO_4$ per acre pH
372	Norfolk sand	5.85	5.00	4.80
373	Ruston sandy loam	5.40	4.65	4.35
374	Orangeburg sandy loam	6.00	5.07	4.75
375	Greenville sandy loam	5.80	5.00	4.77
376	Norfolk sandy loam	5.35	4.70	4.45
377	Decatur silt loam	5.75	5.20	5.05
379	Cecil clay loam	6.15	5.88	5.60
386	Decatur silt loam	5.85	5.45	5.20
387	DeKalb fine sandy loam	5.90	5.15	4.85
419	Mississippi delta soil	6.00	5.65	5.50
420	Tifton sandy loam	5.80	5.40	5.00
421	Portsmouth fine sandy loam	5.15	4.90	4.70
504	Cecil sandy loam	5.75	5.48	5.18
557	Lintonia silt loam	6.40	5.85	5.65

It will be seen that as low a rate of ammonium sulfate fertilization as 500 pounds per acre was sufficient to change the reaction of three of the soils to less than pH 5.0. With double the rate of application the reaction of seven of the soils was below pH 5.0. It will be noticed also that the reaction of some of the heavy soils changed much less than that of the sandy soils receiving the same amount of ammonium sulfate. That is what would be expected from a consideration of the buffer capacity of the soils.

In order to make a quantitative comparison between the buffer capacity of soils and their buffer action toward ammonium sulfate, it was necessary to give a numerical value to the latter. If, as a basis for calculation, it is assumed that all the nitrogen in ammonium sulfate is nitrified with a consequent formation of nitric and sulfuric acid, a value can be obtained giving what may be termed the potential acidity of ammonium sulfate in terms of tenth-normal acid. On the basis of this assumption 660 pounds of ammonium sulfate per acre 2,000,000 pounds is equivalent to 1 cc of normal acid per 100 grams of soil.

Using the above method of calculation, graphs were made of the data obtained by the laboratory method and of that secured by the greenhouse method as reported in Table 3. The buffer capacities of the soils to pH 4.60, 4.80, and 5.25, as indicated by the two methods, were then calculated. The data are given in Table 4.

It will be noted that the H-ion concentrations of the untreated soils given in Table 4 are slightly different than the values given in Table 3. This can be explained by the fact that the former values were secured from determinations on stored samples, whereas the latter were obtained from samples taken from the unfertilized soils in the greenhouse which had been kept moist and grown to crops.

Table 4 gives the specific buffer capacity of the various soils calculated on the basis of the laboratory and the greenhouse method. The data show that the specific buffer capacity values of the greenhouse method, which as before explained were calculated on the assumption that the theoretical amount of acid is liberated from ammonium sulfate, are much greater than those obtained by the laboratory method.

In the last three columns of the table the specific buffer capacity values of the greenhouse method are placed on a relative basis to the laboratory values considered at unity. These, as will be noticed, are given as calculated to three different degrees of acidity. In order to simplify the discussion the term "greenhouse factor" is given to these values.

If the greenhouse factors at pH 4.8 are first considered, it becomes evident that a very uniform value is obtained for the different soils.

In other words, with the exception of one soil there is a very close correlation between the ability of the soils to buffer acids as determined in the laboratory and their ability to buffer the acidity developed from ammonium sulfate.

TABLE 4.—*The buffer capacity of soils as determined by the laboratory method and by the use of* $(NH_4)_2SO_4$ *fertilizer in greenhouse experiments.*

Lab. No.	Soil type	H-ion concentration	Specific buffer capacity to pH 4.8		"Greenhouse factor" at pH values		
			Laboratory method	Greenhouse method	5.25	4.80	4.60
		pH					
372	Norfolk sand	5.65	0.35	1.38	2.7	3.9	6.1
373	Ruston sandy loam	5.40	0.32	0.87	—	2.7	4.4
374	Orangeburg sandy loam	5.75	0.42	1.16	2.9	2.8	3.6
375	Greenville sandy loam	5.75	0.59	1.40	1.9	2.4	3.3
376	Norfolk sandy loam	5.45	0.46	1.31	—	2.7	4.5
377	Decatur silt loam	5.60	1.20	3.16	1.8	2.6	—
379	Cecil clay loam	5.85	1.27	3.39	2.7	2.6	4.3
386	Decatur silt loam	5.95	1.39	3.43	1.8	2.6	—
387	DeKalb fine sandy loam	5.85	0.60	1.67	1.8	2.8	3.8
421	Portsmouth fine sandy loam	5.35	1.16	2.90	—	2.5	—
420	Tifton sandy loam	5.80	0.80[a]	2.00[a]	2.5	—	—
504	Cecil sandy loam	5.90	1.41[a]	2.96[a]	2.1	—	—
Average for all soils					2.2	2.8	4.3

[a] Buffer capacities are calculated to pH 5.25.

It will be noted, however, that the greenhouse factor varies with the pH to which the buffer capacities were calculated. The lower values at pH 5.25 than at pH 4.80 can be partly explained by the fact that the specific buffer capacity of a soil is sometimes slightly less near its original reaction than in a range more removed from this point. It will be noted that pH 5.25 is close to the original reaction of most of the soils. In fact, in a few cases it was so close that calculations could not be made with any degree of accuracy. Another possible reason for the low values and for the less uniform factor is that the data for the greenhouse method were secured from the part of the curves which had few points of reference. Thus, the values are only approximate. They would, no doubt, have been closer to those secured at pH 4.8 if less acid soils had been used and more points had been secured on the curve.

In a few of the soils studied the acidity of the greenhouse soils had developed to pH 4.6 or lower, and thus it was possible to determine the greenhouse factor at this reaction. The last column of Table 4 shows that the greenhouse factors at pH 4.6 are much higher than those obtained at pH 4.8 and 5.25. There are probably several reasons for the higher factor at this high H-ion concentration. One may be that at this high acidity the longer time of contact afforded by the greenhouse method of study causes a relatively greater reaction of the acid with the iron and aluminum compounds in the soil than is obtained in the laboratory method. Hence, a relatively larger greenhouse factor is secured than at pH 4.8 and above. Undoubtedly the most important reason, however, is that complete nitrification of ammonium sulfate does not take place at pH values below 4.8. It was found, for example, that only 39% of the ammonium sulfate applied at the rate of 150 pounds per acre to a sandy loam soil in a greenhouse experiment had been nitrified after three months. This is in accordance with the conclusions of Waksman (6) that in laboratory studies the nitrate accumulation from ammonium sulfate in the soil stops when the reaction reaches pH 4.4 to 4.8.

There are at least two reasons why the buffer capacity of the soil as calculated from the use of ammonium sulfate in greenhouse experiments is higher than that obtained by the laboratory method. First, it is possible that all the ammonium sulfate does not undergo nitrification. Second, the reaction between the soil and the acid formed from ammonium sulfate may go nearer to completion than that between the acid and the soil in the laboratory method. Results secured thus far from a study of this question indicate that the second explanation is probably the more valid.

The question then arises as to whether or not the greenhouse factor will apply equally well to soils fertilized with ammonium sulfate in the field through a period of years. If it does, it should be possible to determine how much ammonium sulfate may be added to a soil in the field before a certain pH is obtained and an injurious acidity for various crops developed.

FIELD EXPERIMENTS

In order to determine whether or not the same factor will apply in the field as in the greenhouse, a study was made of three experiment fields some plats of which had received various applications of ammonium sulfate. It is evident that if buffer capacity determinations are made on the untreated plats it should be possible to calculate how much ammonium sulfate had been added to produce the acidity found. In order to make the calculations, however, it is necessary to know to what depth the acidity was developed and to what extent the ammonium sulfate affected the reaction of each section of the soil profile. Soil samples were taken, therefore, from the ammonium sulfate and check plats in 4- or 6-inch layers. The surface layers to the depth of 12 inches were obtained by digging a small hole 12 inches deep with a spade and taking the samples with a trowel from the sides of the hole. The bottom of the hole was then scraped clean, and the deeper layers obtained by means of a soil auger. Care was always taken to be sure that there was no contamination of the deeper by the surface layers of the soil in sampling.

"SOURCE OF NITROGEN FOR CABBAGE" PLATS

The Norfolk sand on which these plats are located is an extremely poor sandy soil. The surface to a depth of about 8 inches is a brownish yellow medium sand. From 8 inches down it gradually becomes more yellowish and slightly coarser in texture.

This experiment was started in the fall of 1925 by the Horticulture Department. Cabbage was planted in the spring, and a total application of 750 pounds of ammonium sulfate was made during the growing season. Acid phosphate and muriate of potash were also added to the ammonium sulfate plat at the rates of 1,600 and 200 pounds per acre, respectively. After the cabbage crop was harvested, the land was worked and planted to corn without refertilization. The samples for this study were taken during the fall of 1926. Since the check and ammonium sulfate plats are adjoining and five different borings were made on each plat, the variation in the soil between the two plats and in the sampling was reduced to a minimum.

The soil samples were brought to the laboratory and air-dried. H-ion and buffer capacity determinations were then made on the soil from the various depths of the ammonium sulfate and check plats respectively. From the buffer capacity determinations calculations were made to ascertain the amount of ammonium sulfate that would have to be added to bring the soil to the reaction found for the ammonium sulfate plat. In making these and following calculations, the weight of an acre 6⅔ inches of soil was taken to be 2,500,000 pounds for sands or sandy loams and 2,000,000 pounds for soils of heavier texture. The results are given in Table 5.

It will be seen that ammonium sulfate caused an increased acidity of 0.6 pH in the surface soil, of 0.5 pH in the 6- to 12-inch section, and of 0.45 pH in the 12- to 18-inch section. The calculated amount of ammonium sulfate required to cause these changes throughout the soil profile was found to be 624 pounds, whereas the actual amount applied was 750 pounds.

"OLD SOURCE OF NITROGEN" PLATS

The "Old Source of Nitrogen" plats at the Alabama Experiment Station are located on a Cecil sandy loam. The surface soil to a depth of 8 inches consists of a reddish brown sandy loam which increases a little in fineness with depth. At 8 inches the subsoil, consisting of a red clay loam, is abruptly encountered. The subsoil grades into a slightly yellower red clay at 12 to 14 inches and remains about the same to at least 36 inches.

The experiment was started in 1911 with the purpose of comparing sodium nitrate, ammonium sulfate, and calcium cyanamid. The fertilizer application for each crop was as follows:

Plat No.	Fertilizer treatment
1 and 5	160 lbs. acid phosphate; 100 lbs. kainit; 150 lbs. $NaNO_3$
2 and 6	160 lbs. acid phosphate; 100 lbs. kainit; 125 lbs. $CaCN_2$
3 and 7	160 lbs. acid phosphate; 100 lbs. kainit; no nitrogen
4 and 8	160 lbs. acid phosphate; 100 lbs. kainit; 105 lbs. $(NH_4)_2SO_4$

TABLE 5.—*The amount of ammonium sulfate applied in the field as calculated from buffer capacity studies compared with amount actually applied to the "Source of Nitrogen for Cabbagge" plats at Auburn, Alabama.*

Depth in inches	H-ion concentration		Specific buffer capacity to pH 4.8	Pounds per acre of $(NH_4)_2SO_4$ required to produce the acidity found in the field	
	Check plat	$(NH_4)_2SO_4$ plat		Calculated amount	Amount applied in the field
	pH	pH			
0–6	5.50	4.90	0.21	260	750
6–12	5.50	5.00	0.21	204	
12–18	5.45	5.00	0.19	160	
18–24	5.50	5.45	0.19		
Total to a depth of 24 inches				624	750

Oats were grown as the winter crop and sorghum as the summer crop. The yearly fertilizer application was, therefore, twice the amounts indicated above until 1925, when the fertilizer application for the summer crop was discontinued. Sorghum showed marked injury about 1916 on the ammonium sulfate plats and corn was substituted as the summer crop. Corn also showed injury. In 1918, cotton was started. Lower yields were obtained on the ammonium sulfate plats than on the sodium nitrate and calcium cyanamid plats from the start. In 1925, the growing of cotton was discontinued and several rows of various crops grown across each plat. The application of fertilizer to the summer crops was also discontinued at this time. Thus, the total amount of ammonium sulfate applied to plats 4 and 8 was 3,150 pounds per acre.

The samples were taken in the fall of 1926, about one month after the plats had been refertilized for oats. Since the ammonium sulfate may not have nitrified completely by this time, it is probable that

3,045 pounds is a more accurate estimate of the ammonium sulfate that had caused the acidity found than is 3,150 pounds. The latter figure, however, has been used in the comparison.

Table 6 gives the data secured from the study. It will be seen that the laboratory study of the check and ammonium sulfate plats indicates that a total of 2,538 pounds of ammonium sulfate had been applied. The amount applied was actually 3,150 pounds. Remembering that the greenhouse factor varied considerably when the buffer capacity values were calculated to pH 4.60 and that the average value was used in these calculations, it is evident that a good correlation between the two values was obtained.

TABLE 6.—*The amount of ammonium sulfate applied in the field as calculated from buffer capacity studies compared with the amount actually applied to the "Old Source of Nitrogen" plats at Auburn, Alabama.*

Depth in inches	H-ion concentration Check plat	H-ion concentration $(NH_4)_2SO_4$ plat	Specific buffer capacity to pH 4.55	Pounds per acre of $(NH_4)_2SO_4$ required to produce the acidity found in the field: Calculated amount	Pounds per acre of $(NH_4)_2SO_4$ required to produce the acidity found in the field: Amount applied in the field
	pH	pH			
0–4	5.40	4.55	0.40	745	
4–8	5.40	4.55	0.55	851	3,150
8–12	5.00	4.55	0.98	793	
12–16	4.95	4.85	1.26	149	
16–20	4.85	4.80	—	—	
Total to a depth of 16 inches				2,538	3,150

FERTILIZER TEST PLATS, ATHENS, GEORGIA

In addition to the study of the plats at the Alabama Experiment Station, a study was also made on the check and ammonium sulfate plats of the fertility test field of the Georgia Agricultural College at Athens, Georgia.[7]

The surface soil consists of a reddish-brown, heavy, sandy loam. At a depth of about 8 inches a red clay loam is encountered. It gradually grades into a more yellowish red clay at about 12 inches and remains about the same to at least 36 inches.

The test was started in 1914. A three-year rotation of cotton, corn, and oats followed by peas has been maintained. Up to 1926 the ammonium sulfate plat had received a total of 4,800 pounds of acid phosphate, 1,200 pounds of muriate of potash, 1,640 pounds of ammonium sulfate, and 183 pounds of sodium nitrate. In 1926, the nitrogen treatment was changed to 100 pounds ammonium sulfate

[7] The writer is indebted to Prof. Paul Tabor of the Georgia College of Agriculture for furnishing these samples for study.

and 100 pounds of lime were also applied in the row at planting. The samples were taken in the fall of 1926. Since the samples were taken between the rows, the applications of lime and sulfate in 1926 were not considered as influencing the acidity of the samples taken.

A similar study was made as with the plat samples from the Alabama Station, and the results are reported in Table 7. It will be noted that the acidity of the check plats is high and that there is a much smaller change in H-ion concentration as a result of fertilization with ammonium sulfate than in the plats from this station. Moreover, the soil has been affected to a depth of only 8 inches. The reason for this becomes obvious, however, when one considers the higher buffer capacity of this soil and its subsoil. While the soil is regarded as a Cecil sandy loam, similar to that from the "Old Source of Nitrogen Plats" at Auburn, there is quite a marked difference in buffer capacity of both the surface and subsoil samples from these two fields.

TABLE 7.—*The amount of ammonium sulfate applied in the field as calculated from buffer capacity studies compared with the amount actually applied to the fertilizer test plats at Athens, Georgia.*

Depth in inches	H-ion concentration		Specific buffer capacity to pH 4.60	Pounds per acre of $(NH_4)_2SO_4$ required to produce the acidity in the field	
	Check plat	$(NH_4)_2SO_4$ plat		Calculated amount	Amount applied in the field
	pH	pH			
0-4	5.00	4.60	0.88	746	
4-8	5.00	4.60	0.88	746	1,540
8-12	5.05	5.05	1.67	-- -	
12-16	5.35	5.35	---	—	
Total to a depth of 16 inches				1,492	1,540

The calculated amount of ammonium sulfate used is found to be 1,458 pounds as compared with 1,540 pounds actually applied.

GENERAL DISCUSSION

It is apparent from the present study that soils vary widely in buffer capacity. Since it was shown that the buffer capacity determinations made by the laboratory method can be taken as a measure of the buffer action of soils toward the acidity developed by ammonium sulfate, it is evident that we are in a position to answer more definitely the questions regarding the acidifying influence of physiologically acid fertilizers on different soils. Thus, sandy soils, which were found to have a low buffer capacity, were also found to develop a higher H-ion concentration when fertilized with ammonium sulfate than heavy soils similarly fertilized.

From the standpoint of southern agriculture this fact is doubly significant, for large portions of the soils of the cotton-growing states are of a sandy character. Thus, of the 28,229,888 acres of land mapped in Alabama up to 1919, 17,558,395 acres, or 62.5%, consisted of sandy loam or coarser textured soils. Considering the fact that under boll weevil conditions light-textured, well-drained soils are preferable for the growing of cotton and that a much larger percentage of these sandy soils than of the heavy soils are being grown to cotton, it is safe to say that 75 to 85% of the cotton grown in Alabama is grown on sandy soils. This is also true to a large extent of conditions in some of the other cotton-growing states.

This study has also revealed the fact that the character of the subsoil with respect to texture and buffer capacity must be considered in determining how quick a certain acidity is developed in the surface soil from the use of physiologically acid fertilizers. It was found that leaching may cause an increased acidity of the subsoil at the expense of the acidity of the surface soil. Thus, an addition of 750 pounds of ammonium sulfate per acre on a Norfolk sand with a very porous subsoil resulted in an increased acidity of the 12- to 18-inch layer. On the other hand, the acidity developed by the addition of over twice this amount of ammonium sulfate to a Cecil sandy loam at Athens, Georgia, had penetrated to a depth of only 8 inches during a period of 14 years.

The effect of physiologically acid fertilizers on the acidity of the subsoil may, therefore, be of considerable significance. It presents problems that hitherto have not been considered. In the first place it means that if the acidity caused by physiologically acid fertilizers is distributed through, let us say, 12 instead of 6 inches, it will take twice as much fertilizer to produce a given acidity in the surface zone.

Moreover, it raises the question of the injuriousness to crops of the acidity of the subsoil. It seems very probable that the acidity of the subsoil within the root zone will be detrimental to crop growth. This means that lime would have to be added not only to correct the acidity of the surface soil but of the subsoil as well. Another problem would thus be presented from a practical viewpoint, namely, how soon after the application of lime to the surface soil will the acidity of the subsoil be neutralized?

It appears also from the data obtained on the "Source of Nitrogen for Cabbage" plats that on some soils the acidity may possibly leach below the root zone. It must be emphasized, however, that the Norfolk sand on which this experiment is located has a much more sandy and porous subsoil than possibly 80 to 90% of the sandy soils of this state. This is shown to some extent in the buffer capacity data given in Table 2.

Before definite conclusions can be drawn regarding the downward movement of acidity and the problems arising thereform, it is evident that more data must be secured. The writer is continuing this study along these lines.

SUMMARY

A simple and accurate laboratory method for the determination of buffer capacity of soils is described. In a study of the method it was found that whereas the three strong mineral acids gave practically the same buffer capacity values, equilibrium was obtained much quicker with sulfuric than with nitric and hydrochloric acids.

By the use of this method buffer capacity determinations were made on a number of soils from Alabama and other states. The results were expressed according to the numerical method proposed by Charlton, and the values obtained were compared with those found by Charlton and Arrhenius who worked largely with foreign soils. It was found that the buffer capacity values of some sandy Coastal Plain soils are very low. One sandy soil was found to be only one-fifteenth as well buffered as a heavy clay loam from Illinois and only one-thirtieth as well buffered as some of the soils reported by Arrhenius.

The buffer action of 14 soils toward the acidity developed by ammonium sulfate in greenhouse experiments was studied. It was found that the use of 500 pounds of ammonium sulfate per acre caused the acidity of two soils to become greater than pH 4.8, an acidity which is definitely injurious to most crops. The application of 1,000 pounds per acre caused six of the soils to reach this or a lower pH value.

On the assumption that all the nitrogen and sulfur in ammonium sulfate causes soil acidity, the buffer capacity of soils toward ammonium sulfate was compared with the buffer capacity of soils determined by the laboratory method. It was found that there was a close parallelism between the values obtained by the two methods, and that by means of the factor obtained it is possible to determine by the laboratory method the amount of ammonium sulfate required to bring a soil to a definite H-ion concentration.

A study of the acidity developed from the use of ammonium sulfate on three experimental fields substantiated the above conclusions. Thus, the calculated amounts of ammonium sulfate required to bring the acidity to the values obtained were 624, 2,538, and 1,458 pounds per acre as compared with 750, 3,050, and 1,540 pounds, respectively, which were actually applied.

In making the study on the soils from the experimental fields it was found that there may be a movement of the acidity due to ammonium sulfate into the subsoil. Thus, in a very sandy soil the acidity of the subsoil was affected to a depth of 18 inches. On the other hand, the movement downward was very slow in soils having heavy subsoils.

A brief discussion is given regarding the relation of these findings to practical agriculture.

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THE SOIL REACTION OF FIELDS GROWING ALFALFA AND THE USE OF FIELD TESTS IN ITS DETERMINATION[1]

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The acreage of alfalfa is increasing rapidly in the northern part of the bluegrass region of Kentucky. A small part of the crop is grown on land that has been limed. Most of it is grown where the natural reaction of the land is favorable for the crop. The topography of much of this section is that of long, steep slopes with narrow ridge tops. A part has shorter, less steep slopes and the ridges are widened out into considerable areas of undulating land. The soil is of limestone origin.

Growth of alfalfa without liming is attempted for the most part only on the steeper slopes. The undulating land is limed before seeding to the crop. Most of the section can be correctly placed with reference to need for liming for successful growth of alfalfa on the basis of topography. On part, however, the need for liming cannot be determined in this way. Field tests giving reasonably accurate information in placing these doubtful areas would be valuable.

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Limited work previous to that reported in this paper indicated that in fields successfully growing alfalfa the "richorpoor" solution and "soiltex" would give acid tests sufficiently often to reduce considerably their value in this connection.

The work reported in this paper was done primarily to get more information on this point. Tests were made in the field with the "richorpoor" solution, with the "soiltex" test, and with litmus paper. The fields examined were located mainly in Grant County with a few in Pendleton County on the east. Samples of soil were also sent to the laboratory for further work, mainly colorimetric determinations of pH value. The "richorpoor" test was repeated on the soils sent to the laboratory after they had reached air-dry condition. Certain of these soils were also tested with Harper's test solution (3)[3]. Results from the work done in the laboratory are reported in Table 1. In nearly all cases agreement was good between the laboratory and the field "richorpoor" tests, in spite of the fact that most of the field tests were made on soils too wet for tillage operations.

Approximately 100 "soiltex" tests in the surface soil were recorded in fields of alfalfa which had never been limed. The color in 25 of these was blue, in 34 green, in 11 green-yellow, and in 30 yellow. These tests represented a somewhat larger proportion of tests from parts of the fields testing acid than from parts of the fields testing neutral or basic. A considerable number of tests with "soiltex" and litmus paper were not recorded. These were more often tests showing neutral or alkaline reaction. A fair statement probably is that in fields naturally growing alfalfa in this section well-distributed "soiltex" tests will show yellow or acid in one-fourth of the trials on the surface soil.

Sixty litmus paper tests in the field were recorded. Results from the litmus paper tests indicate that on the average this test will show acid reaction somewhat more frequently than will "soiltex." It is to be expected that this would be true from a consideration of the action of the respective indicators used. Litmus has a range from pH 4.5 to 8.3 according to Clark (2), but the useful range is much narrower, particularly for testing soil reaction, and is limited to about pH 6.4 to 7.4. The reaction chart furnished with the "soiltex" outfits used in the tests reported in this paper indicated that "soiltex" had a usable color range on the acid side to pH 4.9. It was found, however, that the usable range extended no farther than pH 6.0.

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[3] Reference by number is to "Literature Cited," p. 356.

TABLE 1.—*Results mainly from laboratory "richorpoor" tests and pH values colorimetrically determined on samples of soil from alfalfa fields which have never been limed with a statement as to alfalfa growth.*

Lab. No.[a]	Richorpoor[b]	Harper's[b]	pH value	Age and nature of alfalfa
1	1	1	6.8	Old; fair to good
2	3	1	6.2	4 years old; fair
3	4		6.1	Small area with no alfalfa in field No. 2.
4	2	1	6.5	5 years old; fair
5	3		6.5	3 years old; poor to fair
6	3		6.0	10 years old; good in past, now largely bluegrass
6a	6		5.9	
6b	6		6.0	
6c	6		5.9	
7	6		6.0	Same field as 6
7a	6		6.1	
7b	1		7.2	
8	1		7.6	Sown in spring; good
8a	1		7.6	
8b	1		7.5	
8c	1		7.2	
9	1		7.4	Same field as 8
9a	2		6.9	
9b	1		7.6	
10	2	1	6.9	Same field as 8
10a	1+		7.0	
10b	1		6.9	
11	1		6.9	Very old, mainly bluegrass
12	2		6.8	Old; fair
13	2		6.6	Old; fair
14	2	1	7.0	Sown in oats in spring; good
15	3	2	6.1	6 years old; mainly good
16	2		6.4	5 years old
17	2		7.3	Sown in spring; good
17a	1		7.8	
17b	1		7.9	
18	6		6.1	Same field as 17
18c	4	4	6.5	
19	5		6.1	2 years old
20	5		5.5	6 years old; fair to good
21	2	1+	7.0	Same field as 20
21a	1		7.3	
22	3	1+	6.6	Old
23	2		7.0	Sown in spring; good
24	1		7.4	Same field as 23
25	2		7.2	14 years old; good in past, mainly bluegrass now

TABLE 1.—*Concluded.*

Lab. No.[a]	Richorpoor[b]	Harper's[b]	pH value	Age and nature of alfalfa
25a	1		7.1	
26	3	2	6.5	12 years old; still fair stand
27	2	1+	6.9	3 years old; good alfalfa
27a	3	4	6.1	
27b			7.8	
28	2		7.0	4 years old; good alfalfa
29	4	4	6.1	8–12 years old; good
30	2		6.6	Same field as 29
30a	3	2	6.5	
30b	1		7.7	
31	3	4	6.5	Same field as 29
31a	2	2	6.6	
31b	2		7.2	
31c	1		7.3	
32	2		7.0	Good
32a	4	4	6.5	
32b	1		7.4	
33	2		6.6	
33a	2		7.3	
34	4	4	6.2	Good
34a	4	4	5.8	
34b	2		7.2	
35	2		6.7	6 years old
35a	1		7.0	
35b	1		7.0	
36	4		6.0	Old; good
36a	1		7.3	
37	4		6.5	Same field as 36
37a	5		6.6	
37b	4		6.6	

[a] Numbers without letters indicate surface soils; the letters indicate, approximately, a, 12-inch depth; b, 24-inch depth; c, 36-inch depth.

[b] The numbers indicate colors secured as follows: 1, no color; 6, a dark red color about the maximum amount of color to be expected with acid soils; 2, slightly pink; 3,4, and 5 intermediate shades between 2 and 6 in order given.

The fact that litmus gives acid tests at a slightly higher pH value than bromthymol blue, the indicator in "soiltex", lessens its relative value as a test for soil acidity. The color change of litmus paper is also harder to read in the field than is that of "soiltex."

Study of the results in Table 1 shows that the "richorpoor" solution used remained colorless or gave only a very faint pink color at pH 7 (or above) with these soils. The entire range of color, from colorless to very dark red, occurred from pH 7.0 to pH 6.0. This is the same range covered by "soiltex" between the neutral and acid points.

"Richorpoor" solution, however, gave a better separation in the more acid soils than "soiltex." Correlation between pH value and color produced with "richorpoor" solution was only fair. Certain of the soils were tested with Harper's (3) test solution. This solution gave less acid tests with several of the soils than the "richorpoor" solution and in this respect was preferable. When any one of the tests ("richorpoor", "soiltex," or litmus paper) shows a neutral (or alkaline) reaction, it is apparently certain that liming is not needed for successful alfalfa growth on these soils. On the other hand, the fact that the tests showed acid on the surface soil did not always mean that liming was required. "Richorpoor" was slighty better in this respect than "soiltex." Both "richorpoor" solution and "soiltex," however, and litmus paper more frequently, gave acid tests sufficiently often in fields of good alfalfa to lessen materially their value for use in ascertaining need for liming on these soils for this crop. As will be noted presently, there is the possibility that the successful alfalfa growth where the tests gave acid reaction on surface soils was due to neutral or basic under-soil strata.

A study of the pH value of the soil samples from the alfalfa fields as shown in Table 1 is interesting. These samples were not from locations equally distributed over the fields, but to a considerable extent were from places where the field tests showed acid reaction and therefore cannot be used to give the average pH value of the fields. They do give a correct range of pH values. Bryan (1), in sand culture work, found that alfalfa made its best growth at pH 7 to pH 8. Much smaller growth was made at pH 6 and the plants were somewhat yellow during their entire growth. Still smaller growth was made at pH 5.0 and none at pH 4.0.

Joffe (4) reports results from pot work with soil showing that growth occurred with as low a pH value as 3.8. Growth increased up to pH 6.5.

The pH value of the surface soils in the alfalfa fields studied in this work ranged from about pH 6.0 to pH 7.6 with the exception of No. 20 where the value was pH 5.5. Soils testing above pH 7.0 usually effervesced with hydrochloric acid due to presence of carbonates from thin strata of marl exposed on the slopes. Joffe reports that the alfalfa plants at the low pH values (pH 3.8 to 4.3) required some time in establishing themselves, making very little growth during this time but making good growth thereafter. This fact has also been observed in pot work with alfalfa and red clover by the senior writer. Growth of these legumes but rarely succeed in soils of the same low pH values under field conditions, since the combination of other poor growth conditions, frequently lack of moisture, with unfavorable soil reaction results in the death of the plants during the period of establishment.

In the case of alfalfa growing in areas with the surface soil at the lower pH values (Table 1), under soil strata were studied and usually within a depth of 36 inches soil of much higher and perhaps even of a neutral or basic pH value was found. It cannot be said definitely, therefore, that in the absence of the opportunity of the alfalfa plant to reach areas of higher pH value by considerable root penetration that satisfactory growth would have been made at the lower pH values of the surface soils. The crop, however, germinated and made its early growth presumably when most sensitive to acid soil reaction unaided by these areas of higher pH value.

SUMMARY

"Richorpoor" solution, "soiltex," and litmus paper were used in testing the reaction of soil in alfalfa fields in the northern part of the bluegrass region of Kentucky. The fields from which results are given had never been limed. The purpose of the study was to find out the extent to which the tests could be used in determining need for liming for alfalfa on doubtful areas in this section. Both "richorpoor" solution and "soiltex," and litmus paper more frequently, were found to give acid tests on the surface soil sufficiently often in fields of alfalfa in this section to lessen materially their value for this purpose.

The surface soils of the alfalfa fields were found to range in pH value with one exception from 6.0 to 7.6. In the case of the surface soils with the lower pH values under soil strata were studied, and usually within a 36-inch depth soil of basic or neutral pH value was found.

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NOTE

A METHOD OF HARVESTING GRAIN IN VARIETY TESTS

The Department of Agronomy of the Delaware Experiment Station has been confronted for several seasons with the problem of storage of wheat plants grown in variety tests until they are ready to thresh. The storage space available was not large enough and there was no prospect of obtaining more space so a scheme was devised whereby the plants from all the varieties could be adequately cared for until threshing time. The method devised proved to be so satisfactory that it is submitted for the benefit of those who may have similar needs.

The variety test plats consist of four rows of grain 8 inches apart and 8 rods long. The varieties are tested in duplicate with a check every fifth plat. The harvest from one of these plats makes about 4 bundles. Four bundles is not enough to shock separately and when two or more plats are shocked together it causes confusion, introduces errors, and makes it difficult to locate the duplicates.

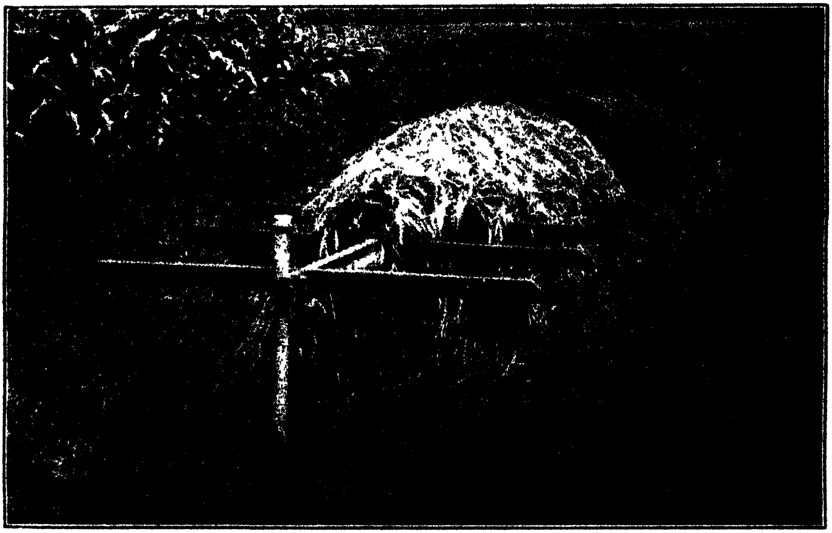

FIG. 1.—Showing rack in use.

With these conditions in mind a portable rack was built as is illustrated in Fig. 1. This rack consists of four 10-foot sections. The dividing rail is 2" x 4" timber set on edge and is mortised every 2½ feet for the cross rails. The cross rails are made of 2" x 3" timber 5 feet long and mortised midway to rest on top of the dividing rail. This makes a compartment 2½ x 2½ feet and will hold 4 or 5 bundles of grain. The dividing rails are 10 to 12½ feet long, depending on the number of cross rails to a section. (See Fig. 2.)

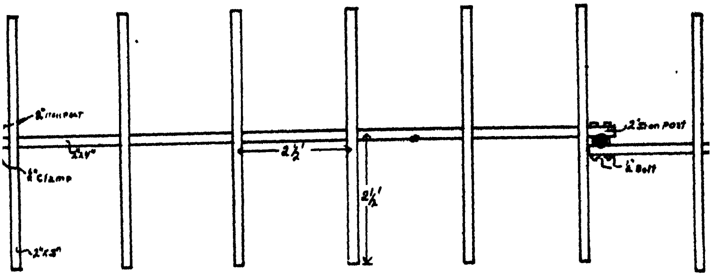

FIG. 2.—Diagram showing construction of rack.

As the plats are harvested the grain is set up in order in the compartments, the duplicates are set up in the same order, and the entire rack is then covered with a canvas. When the grain is ready to thresh the duplicates are hauled in together and threshed with one thorough cleaning of the machine. There may be a slight amount of mixing of grain in the rack but this can be eliminated at roguing time.

Four sets of these racks consisting of four sections each and the canvas for covers cost $100. This is enough space for 72 plats in duplicate and the ease with which the plats have been cared for and harvested have made it worth while.—GEO. L. SCHUSTER, *Agronomist, Delaware Agricultural Experiment Station, Newark, Del.*

AGRONOMIC AFFAIRS

A CORRECTION

The attention of the Editor has been called to the fact that the statement in the Book Review of Engledow and Yule's "The Principles and Practice of Yield Trials" which appeared in this JOURNAL for January, 1927, that the pamphlet "is available for free distribution," while based on information which accompanied the copy submitted to the JOURNAL, is evidently an error, as members of the Society who have sent for a copy have been billed for two shillings therefor.

POSTPONEMENT OF SUMMER MEETING OF THE CORN-BELT SECTION OF THE SOCIETY

Because of numerous conflicts in dates, and with the approval of the Executive Committee of the Society, the annual summer meeting of the Corn-Belt Section of the Society, which was to have been held in Ohio in June, 1927, has been postponed until a similar date in 1928.

REPORTS OF EXPERIMENTS IN COTTON GROWING

The Empire Cotton Growing Corporation, Millbank House, Millbank, London, S. W. 1, has printed in pamphlet form the "Reports Received from Experiment Stations, 1925–1926." These experiment stations include one in Australia, eight in Africa, and one in the West Indies. The report is for sale by the Corporation at 2s. 6d, post free.

NEWS ITEMS

R. P. BARTHOLOMEW and G. A. Jansen have been appointed assistant professors of agronomy at the University of Arkansas and assigned both teaching duties and experiment station research work.

M. N. WALKER was appointed Assistant Cotton Specialist for the Tropical Plant Research Bureau to carry on physiological and pathological studies with cotton in Cuba, beginning December 1, 1926.

J. B. HESTER has been appointed Assistant Chemist at the Texas Agricultural Experiment Station to have charge of investigations in soil chemistry.

D. D. HILL has been appointed Instructor in Farm Crops in the College and Assistant Agronomist of the Experiment Station at Corvallis, Oregon.

HARRY V. HARLAN, Senior Agronomist, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, addressed a meeting of the Society of Sigma Xi at Minneapolis, Minn., on February 14, on the subject "Agriculture of North Africa and Abyssinia." On February 16 he delivered the same address before the Society of Sigma Xi in its meeting at Ames, Iowa.

W. H. Tisdale, Pathologist in charge of Cereal Smut Investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry, resigned on December 15, 1926, to accept a position with the E. I. du Pont de Nemours Company, Wilmington, Del.

F. W. McGinnis, Assistant Professor in Farm Crops, at the University of Minnesota, resigned February 1, 1927, to accept a position with the farm loan department of the Aetna Life Insurance Company.

G. Nilsson-Leissner, assistant in plant breeding at the Plant Breeding Institute, Svalof, Sweden, and fellow of the International Education Board, has completed a year of research and study with the plant breeding department at the University of Minnesota and returned to Svalöf in February.

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SYMPOSIUM ON "SOIL ORGANIC MATTER"

Leader: Firman E. Bear, Head of the Department of Soils, Ohio State University.

1. "Some Physical and Physico-Chemical Properties of Soil Organic Matter." B. A. Keen, Rothamsted Experiment Station.

2. "Organic Matter Supplied in Crop Residues." E. E. DeTurk, Illinois Agricultural Experiment Station.

3. "Organic Matter Requirements of Soil under Various Climatic Conditions." J. C. Russel, Nebraska Agricultural Experiment Station

4. "Soil Organic Matter and Manurial Treatments." J. W. White, Pennsylvania Agricultural Experiment Station.

5. "The Chemical Composition of Soil Organic Matter as Related to its Effectiveness." F J. Salter, Ohio State University.

1. SOME PHYSICAL AND PHYSICO-CHEMICAL EFFECTS OF SOIL ORGANIC MATTER[1]

B. A. KEEN[2]

When agricultural science began to emerge in a recognizable form at the beginning of the last century, the importance of organic material in soil fertility was already generally accepted. "Humus"—decomposed plant and animal residues—was supposed to be the direct food of plants. The effects of this material in improving the physical properties of the soil, although known to agriculturists, were not demonstrated by laboratory methods until Schubler (1)[3] in 1838, and, to a lesser extent, Davy (2) in 1813 had published their researches. Although this work aroused interest, its effects were soon overshadowed by the famous pronouncement of Liebig in 1840 and the rapid development of the Rothamsted experiments in plant nutrition by Lawes and Gilbert. Consequently, the physical factors fell somewhat into the background until comparatively recent times. The revival may be associated with the work of Hilgard, Whitney, and especially King, in America, and in Europe with the contributors to Wollny's *Forschungen auf dem Gebiete der agrikultur Physik* (1878–1898).

As might be expected the physical properties of soil organic matter received considerable attention, and some degree of numerical precision was thus given to the generally known effects under field conditions. The purpose of the present paper is not to tabulate these results, which have long since taken their place in the text-books, but to discuss some of the problems that have arisen with the rapid development of soil science in the past few years.

In the first place the complexity of the soil organic matter introduces corresponding complexities in any attempt to formulate quantitative physical relationships. The physicist usually limits himself to well-defined and reproducible material for his investigations, but soil organic matter consists of crop residues, such as stubbles, farmyard and other organic manures, animal excreta, etc., all of which vary widely in composition, in various stages of decay and degradation under the action of chemical and biochemical agencies. For our purpose it is sufficient to consider the beginning and end stages only.

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[1] Paper read as a part of the symposium on "Soil Organic Matter" at the meeting of the Society held in Washington, D. C., November 19, 1926.

[2] Assistant Director, Rothamsted Experimental Station, Harpenden, England.

[3] Reference by number is to "Literature Cited," p. 368.

Fresh organic matter, typified by newly made farmyard manure or a green manure crop just plowed in, has predominantly a mechanical effect on the soil. The volume of unit weight is much increased, because the stalks and fibrous material hold the soil clods apart, and drainage and aeration are made easier. On heavy soils the channels do not entirely fall in even when the rotting of the material is well advanced; hence the value of fresh or "long" manure on heavy soils in the autumn. On the other hand, light sandy soils, where drainage is naturally easy, would not be improved by such treatment. In their case the well rotted or "short" manure is found to be far more effective, for it has the opposite effect of providing gelatinous colloidal material, which has a high capacity for water and also serves to hold the soil particles together into aggregates, and thus, indirectly, to improve the water-holding ability of the soil. The rotted material is generally referred to as "humus." From the physical viewpoint it may be regarded as a fairly homogeneous material of a gel-like nature displaying marked colloidal properties. Direct study of the material apart from the soil, of which it forms an intimate part, is not possible at present, and its physical properties must be inferred from direct observations on the soil itself.

The well-known effect of increasing the moisture content of soil is a case in point. The usual illustration given in this connection is the comparison between the moisture contents of the unmanured and farmyard manure plats on the classical Rothamsted experimental fields. The latter has, on the average, 5% additional moisture compared with the former. The comparison is, however, somewhat abnormal, as the dunged plat has received 14 tons per acre of farmyard manure annually for many years. In ordinary farming conditions the difference would be less marked. In any case the extra water available for plant growth is not necessarily the full amount of this difference.

Measurements of the moisture contents at different vapour pressures (3) give useful information in this connection. Thus, a comparison of the farmyard manure and unmanured plats of the Hoosfield permanent barley experiments showed that, for any given vapour pressure, the farmyard manure plat had a higher equilibrium moisture content than the unmanured. Thus, at half the full vapour pressure, or in other words, 50% relative humidity, to which the usual "air-dry" condition roughly approximates, the unmanured soil contained about 2.2% of water and the farmyard manure soil about 3.0%, a difference of 0.8%. This difference increased steadily with increasing vapour pressure, and at 90% relative humidity amounted to 1.7%.

Between 90% and saturation vapour pressure the difference increases owing to the asymptopic nature of the vapour pressure—moisture-content curves. Hence, an appreciable fraction of the 5% extra water already mentioned appears on physical grounds to be unavailable to plants, since, according to Alway (4), water below the hygroscopic coefficient[4] cannot be utilized. The matter becomes exaggerated in peat, fen, or truck soils owing to the large amount of organic matter present. Some years ago Crump (6) suggested that an expression of the water content, superior to the usual method, could be obtained by a study of the ratio $\frac{\text{water content}}{\text{loss on ignition}}$, which he called the "coefficient of humidity." He found that successive layers of a given moorland soil, which differed widely in both actual moisture content and organic matter, gave sensibly the same coefficient of humidity, and could therefore be considered, at least in a qualitative sense, as of equal physiological moistness.

The application of this idea to mineral soils presents difficulties, as the loss on ignition also includes water of combination from the clay, and although Crump's preliminary data appeared promising they have not been further developed. It would appear from general experience that soil organic matter holds from three to four times its weight of water. The field observations of Alway and Neller (7) on adjacent plats of different organic matter content may be cited as typical.

Some early experiments of Luxmoore (8), working at Reading in England, are of special interest in this connection. He worked on a large number of Dorset soils and arrived at his conclusions, not by the development of accurate exprimental technic, but from a statistical analysis of the data obtained from simple measurements. He showed, for instance, that the joint contribution of organic matter and mineral particles to the hygroscopic capacity of a soil is more than additive, and he suggested that the reason was to be found in the organic material being more effective than the coarse mineral particles in keeping the finer particles apart from one another and thus better able to exercise their strong surface attraction for water vapour.

There was also evidence to show that the hygroscopic power of organic matter varied with its source. The whole investigation is an excellent early example of the use of statistical methods in agricultural research. Such methods have become an essential feature of biological research in agriculture (9), where the conditions are so complex that the experimental data are normally only of qualitative significance. They are also capable of affording useful information to the soil physicist and chemist.

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[4] This term is open to serious objection, both on theoretical and experimental grounds. See Puri (5).

In the case of soil organic matter, as already mentioned, the humus is such an intimate portion of the general colloidal complex that its direct effects can only be inferred. Although it cannot be removed unaltered and studied apart from the soil, a considerable advance would be possible if some method were available which would leave the soil itself comparatively unaltered except for the removal of the organic matter. Such a possibility is opened up by the use of hydrogen peroxide, introduced by Robinson (10) and now included, after exhaustive trial, as part of the new official method of mechanical analysis adopted by the Agricultural Education Association of Great Britain (11).

This treatment removes, either as gas, or as water-soluble material, practically the whole of the organic matter, with the exception of structural material that can have little influence on the properties of mineral colloidal matter. It is, therefore, possible to study the soil before and after peroxide treatment, and hence, to infer the influence of the humus, provided the mineral portion of the soil has remained unaffected by the treatment with peroxide. So far as any gross alteration in properties is concerned, this assumption is justified. The sole chemical effect of organic matter appears to be the dissolving of a small amount of sesquioxides and, to a lesser extent, silica, the total amounting to only 2 to 3% of the original weight of the soil (11). There remains, of course, the possibility, only too well known in colloid science, of a considerable change in physical and physico-chemical properties following on a relatively small chemical change; but, while admitting the possibility, we may still reasonably hope to obtain valuable information by comparing the physical behavior of soil before and after the peroxide treatment. An extensive investigation of this nature is at present being carried out at Rothamsted. Some 40 different mineral soils of widely different origin and properties were selected and a certain number of physical constants were determined for each soil. Evidence has been obtained indicating that the moisture content at 50% relative humidity is controlled largely by the clay content of the soil, while the "upper limit of plasticity" (12), i. e., the moisture content in a plastic mass of soil when it does not stick unduly to the hands, is closely related to the loss on ignition. This is a suggestive differentiation on which considerable light should be thrown when the corresponding data for the peroxided soils are available.

It is especially necessary to bear in mind constantly the intimate association of clay and organic matter in all studies of the physical properties of colloidal clay. Gile's (13) figures for the analysis of colloidal material obtained from various soil types show that they all contain organic matter, the percentage being of the same order as would be expected in the original soil. In view of the Rothamsted results just mentioned, there is reason to suspect that the tests evolved for measuring both the amount and properties of the colloidal clay are affected to varying degrees by the ratio of organic to inorganic colloid, as well as by the known variations in the chemical composition of the colloidal material. I am indebted to Dr. Haines of this Station for some preliminary figures which bear on this point. Colloidal clay from the continuous mangold plat on Barnfield, which annually receives 14 tons per acre of farmyard manure, was extracted from the soil with the Sharples Super-Centrifuge. One portion was treated with peroxide and the remainder was untreated. Measurements of cohesion (14) and of shrinkage (15) were made on both portions, using the technic already devised by Haines. The cohesion values at different moisture contents were substantially unaltered by the removal of organic matter, but there was an indication that while at the low moisture contents the cohesion of the treated colloid was slightly greater than that of the original colloid. At higher moisture contents the reverse was the case. The moisture content at which residual shrinkage began, i. e., the point at which the loss in volume of the slowly drying clay block began to be less than the corresponding volume of water evaporated, was markedly affected by the peroxide treatment, being reduced to 2.8% against 5.0% with the untreated clay. This difference was also reflected in the pore space of the oven-dry blocks and their specific gravity. The effect of treatment with peroxide on other tests that have been applied to colloidal clays for purposes of classification is worthy of full investigation, for, although the above figures are preliminary measurements needing cautious interpretation, they are certainly suggestive when the comparatively small differences in the loss on ignition values are considered. The untreated clay gave a figure of 15.2% and the treated clay a value of 13.5%.[5]

The intimate association of organic and inorganic colloidal material that has been stressed in the consideration of the physical properties of soil organic matter is equally important in any examination of its physico-chemical properties. This is especially true of the absorbing complex in the soil that has assumed great importance recently in connection with the development of base exchange studies. It is not my purpose to enter into this work, because it has already been dealt with in an earlier symposium of this Society and is the subject of an excellent General Discussion recently held by the Faraday Society of London (16). It is clear that we must consider, in all such questions, an absorbing complex that may range from inorganic, in the case of a soil practically devoid of humus, to organic, in the case of a peat soil. Any soil, therefore, contains its own particular proportion of anions (of the clay and humus acids) with which, in the outer portion of the electrical double layer, are associated the exchangeable cations, including hydrogen. The method developed by Hissink (16) enables a measurement to be made of the amount of exchangeable cations and of the unsaturated acids present, the sum being the total acid value of the absorbing complex. The division of this total among the clay and humus portions of the complex presents a number of important problems of obvious practical significance.

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[5] The residues after ignition showed differences in appearance that are being investigated further.

Robinson (17) has proposed the extension of his original use of hydrogen peroxide to this question by determining the drop in the total acid value of the soil after the organic matter has been removed by the peroxide. He has noted that the acid value of Welsh soils appears to be due largely to humic material, and further, these soils may be unsaturated to a considerable degree without showing signs of infertility. It is not possible at present to say whether this is due to free humus acids being less harmful than free clay acids, or whether it is because calcium "humates" are better able to support plant nutrition than the calcium salts of the clay acids.

Another important physico-chemical property of humus material is its behavior as a protective colloid to the clay particles. Much work has been done on this, especially in relation to the corresponding field problems of soil tilth and the formation of pans. Although the actual effects are obvious enough, and explicable in broad outline in terms of colloidal behavior, no quantitative explanation of the experimental data has yet been made, nor is it likely that any will be forthcoming until the general question of flocculation and deflocculation of clay has been placed on a more systematic basis.

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2. ORGANIC MATTER SUPPLIED IN CROP RESIDUES[1]

E. E. DeTurk[2]

INTRODUCTION

One of the important effects upon the soil of bringing it under the plow is the acceleration of oxidative processes and the consequent decline in the amount of soil organic matter. Recognizing the importance of offsetting this destruction of organic matter, the Illinois Experiment Station has for many years urged upon the farmer the necessity of replacement to some extent of the organic materials thus destroyed by whatever means are at his disposal and practicable as to application.

With this thought in mind, the soil fertility experiments carried out upon the various experiment fields were either laid out originally or later modified in such a way as to provide for regular additions of organic materials to the soil. These were to be made in the form of farm manure in the livestock system of farming; while in the grain system, the organic matter was supplied by the return to the soil of such materials as cornstalks, straw of small grains, clover or soybean straw, second growth of clover, and legume green manure crops grown for the purpose. On all of the fields used in the study to be described the soil is too acid to grow satisfactory green manure crops of sweet clover without liming, except the Clayton field, which in some years makes a poor growth but usually none. These fields thus afford an opportunity for determining the effect of crop residues, which are for the most part nonlegumes, upon organic matter accumulation. This is done by a comparison of the untreated check plats with those receiving crop residues alone.

EXPERIMENTAL METHODS

Samples of soil were obtained from seven experiment fields in which the above-mentioned comparison is possible. Results from the Morrow plats at Urbana are added for reasons to be explained later. These fields were selected, in the first place, upon a basis of soil uniformity. Only those fields were sampled which contained four or more series in which the plats to be sampled were of the same soil type as determined by the classification published in Illinois Agricultural Experiment Station Bulletin 273. Only those series of a given field were used which had the same type in the plats sampled. Upon this basis fields were selected representing different soil types ranging in organic matter content from low to fairly high amounts.

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[1] Paper read as a part of the symposium on "Soil Organic Matter" at the meeting of the Society held in Washington, D. C., November 19, 1926. Contribution from the Divison of Soil Fertility, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Agricultural Experiment Station.

[2] Professor and Chief in Soil Technology.

Samples were obtained from the experiment fields at Oquawka, Palestine, Lebanon, Odin, Oblong, Clayton, and the Davenport plats at Urbana. The Oquawka field consists of dune sand terrace (Plainfield sand). The soil is for the most part uniform. Four series were sampled. No samples were obtained from series 100 because of the steep slope and the possibility of excessive surface washing. Series 300 was not used because in a previous experiment a drab clay soil had been applied to these plats a few years ago. The soil of the Palestine field is brown sandy loam of rather coarse texture, probably Plainfield sandy loam. All five series were sampled. The soil of the Lebanon field is mapped as grayish brown silt loam on tight clay (Grundy silt loam, grayish phase). This field is quite uniform as to soil and all four series were sampled. Gray silt loam on tight clay is represented by two fields, Odin and Oblong, all four of the series being sampled on each field. The portion of the Clayton field used in this study is brown silt loam on clay (Grundy silt loam). All four series were sampled. However, in the 100 series only the south halves of the plats were sampled (105 and 106) because of the encroachment of another type toward the north end. In the Davenport plats, the check and residue plats, respectively, are plats 1 and 2 at the north side of the field. This portion of the field consists of brown silt loam (Muscatine silt loam). The five series are subdivided, making essentially ten. Of these, seven were sufficiently uniform for use.

All the samples except those from the Morrow and Davenport plats were taken in the summer of 1926. They were taken with an augur in two depths, the first 0 to 7 inches and the second 7 to 14 inches, provided the latter depth did not include any of the "B" horizon. Care was taken to exclude the "B" horizon in all cases. Twelve systematically distributed borings were taken on each plat. They were thoroughly mixed and the sample for analysis was taken from this composite. The Davenport and Morrow plat samples had been taken in 1923 in two depths, viz., 0 to 7 inches and 7 to 20 inches. The second stratum included in these cases varying proportions of material from the "B" horizon. A study had previously been made on the Morrow plats of the number of borings required for a given degree of accuracy. It was found that any number of borings greater than seven gave a probable error of less than 1% of the mean. This would be equivalent to an error ranging from 65

TABLE 1.—*Organic carbon content of untreated and residue plats of some Illinois experiment fields, expressed in percentage of water-free soil.*

Series	Depth in inches[a]	Oquawka		Palestine		Lebanon		Odin		Oblong		Clayton		Davenport plats		
		None	Residue	None	Residue	None	Residue	None	Residue	None	Residue	None	Residue	Series	None	Residue
100	0–7	——	——	0.503	0.498	1.233	1.343	1.198	1.259	1.425	1.458	2.059	2.145	100 E	2.906	3.110
	7–14	——	——	0.332	0.335	0.925	0.893	0.711	0.782	0.782	0.940	1.497	1.530		2.127	2.113
200	0–7	0.297	0.335	0.484	0.476	0.928	0.976	1.020	1.352	1.352	1.392	2.143	2.165	200 E	2.401	2.640
	7–14	0.218	0.179	0.230	0.254	0.731	0.711	0.703	0.671	0.887	0.749	1.163	1.647		1.860	2.911
300	0–7	——	——	0.429	0.487	1.149	1.205	1.105	1.236	1.427	1.552	2.009	2.192	200 W	2.957	2.903
	7–14	——	——	0.225	0.225	0.984	0.905	0.812	0.704	0.970	1.061	1.669	1.667		2.509	2.347
400	0–7	0.457	0.511	0.701	0.609	1.054	1.240	1.201	1.176	1.339	1.419	2.090	2.137	300 W	1.981	2.033
	7–14	0.351	0.357	0.380	0.281	0.803	0.906	0.912	0.669	0.712	0.715	1.618	1.547		1.567	1.500
500	0–7	0.272	0.319	0.522	0.605	——	——	——	——	——	——	——	——	400 E	2.698	2.704
	7–14	0.256	0.284	0.257	0.346	——	——	——	——	——	——	——	——		2.679	2.264
600	0–7	0.277	0.294	——	——	——	——	——	——	——	——	——	——	500 E	2.790	2.701
	7–14	0.181	0.239	——	——	——	——	——	——	——	——	——	——		2.800	2.226
	0–7	——	——	——	——	——	——	——	——	——	——	——	——	500 W	2.610	2.726
	7–14	——	——	——	——	——	——	——	——	——	——	——	——		2.429	2.075
Mean	0–7	0.326	0.365	0.528	0.535	1.091	1.191	1.131	1.256	1.386	1.455	2.075	2.160		2.620	2.688
	7–14	0.251	0.265	0.285	0.288	0.838	0.854	0.784	0.708	0.838	0.866	1.487	1.598		2.352	2.087
Excess in residue plats	0–7	0.039		0.007		0.100		0.125		0.069		0.085			0.039	
	7–14	0.014		0.003		0.016		−0.076		0.028		0.111			−0.265	
Odds	0–7	124		1		37		9		41		20			4	
	7–14	3		<1		2		4		1		3			17	

[a] Except Davenport plats which are 0–7 inches and 7–20 inches.

to 600 pounds of organic carbon in two million pounds of soil, depending upon the total content of organic carbon. The probable error for 12 borings was 0.76% of the mean or 50 to 450 pounds of organic carbon per acre. It was assumed, without a separate study of the soil variation within the different plats on each of the fields, that composites made up of 12 borings would give samples sufficiently representative of the soil of the various plats for the purpose of this study.

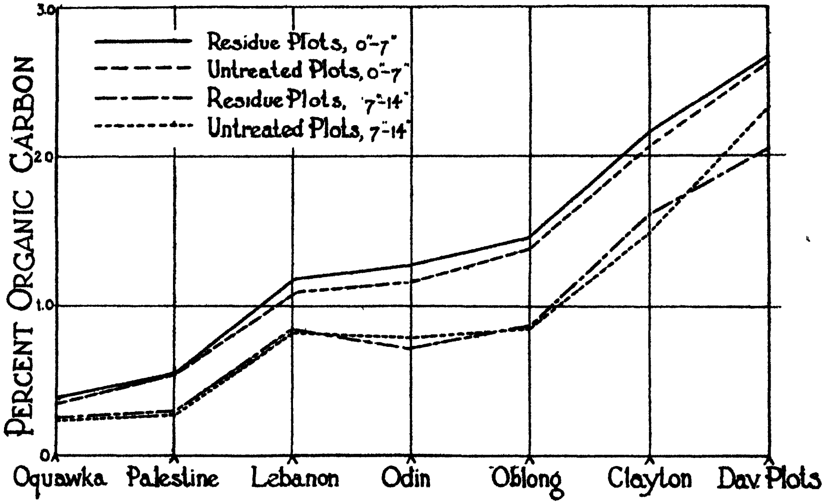

FIG. 1.—Organic carbon content of untreated and residue plats of some Illinois experiment fields.

The samples were air-dried and determinations of total carbon made by the peroxide fusion method. Since all the soils were non-carbonate soils, no deductions were necessary on account of the carbonate factor. Moisture determinations were made and the results computed to the water-free basis. The results are presented in Table 1, and the summarized data, obtained by averaging the results from all series of each field, are shown graphically in Fig. 1.

DISCUSSION OF RESULTS

MAGNITUDE OF ACCUMULATIONS

The data from the seven experiment fields studied indicate that the amount of organic carbon accumulated in the soil from the crop residues added is comparatively small in those cases where any accumulation is shown. Out of the 32 comparisons on different fields gains are shown in 26 cases, and no gains, indicated by a negative, in the other 6. In several of these 26 cases the gains are too small or too irregular to be of any significance. Most of the effect of the crop residues, which can be measured by chemical analysis, is confined to the 0- to 7-inch stratum. The figures for the second stratum do not show consistent increases on any one of the fields studied. This is to be expected since the crop residues are practically all incorporated in the stratum turned by the plow, which probably approximates 7 inches, and have no opportunity to move downward until decomposition has proceeded to such an extent as to produce soluble and leachable products.

The accumulated organic matter in these soils, at the time of sampling, was largely residual material remaining after the subsidence of active biochemical changes occasioned by fresh additions. This statement will be more clearly understood in view of the fact that during 1921, 1922, and 1923 the return of wheat and oats straw as crop residue was discontinued on all of the fields under consideration, with the exception of Oquawka and Palestine, these being the two sand fields. Thus, with the exception of these two fields, the only sources of fresh organic matter at present are cornstalks, roots and stubble, and weeds.

It was considered desirable to obtain some measure of the significance of the data presented. Two methods were available. One was to compute the probable error of the mean of the check plats and of the residue plats of a given field, and from that the probable error of the difference between them The other was to apply Student's method. The latter was used. It appeared to be the more suitable for the following reasons: The number of results from these fields to be included in a probable error determination ranges from four to seven, a number of values too small to be used with satisfaction in this formula. Another consideration of more importance is the location and arrangement of the plats. The different series of plats in the various fields are located in various positions with respect to each other. Even when placed regularly, the maximum distance between two like-treated plats is upwards of a quarter mile in some cases. This arrangement allows the factor of soil heterogeneity to play an unwarranted rôle in enlarging the probable error. On the other hand, in every series studied, the two plats being compared, numbers one and two or five and six, were long, narrow plats lying adjacent to each other along the long dimension. These would seem to form somewhat true pairs, a situation in which Student's method would afford the more accurate measure of significance of the results. While contiguous position of the plats in these pairs would not of itself necessarily indicate their greater natural similarity to each other than plats arranged differently, an inspection of the data for organic carbon in the upper stratum of these plats does indicate that they are naturally paired off in this way. By this method it is seen that in four of the fields studied, namely, Oquawka, Lebanon, Oblong, and Clayton, the increases in organic carbon are backed by odds of 20 or more. These cases all occur in the surface 7 inches. In the 7- to 14-inch stratum a superficial inspection of the data makes it obvious that there are no significant gains in organic carbon in the residue plats. The odds were computed, however, and the highest value found was 17.4:1 in the Davenport plats, the others all falling below 5:1.

DECOMPOSITION OF ORGANIC MATTER

When the small amounts of accumulated organic matter are considered in comparison with the amounts which have been added to the residue plats in excess of the untreated plats, it is obvious that the organic materials added have undergone rather thorough decomposition. If the gain in soil organic carbon be converted to pounds per acre and multiplied by the factor 1.724, an approximate indication is obtained of the organic matter accumulated. If, then, this is compared with the amount of residues added, the percentage of the latter retained may be estimated. This has been done for the four fields giving significant increases and the results are presented in Table 2, giving each series separately as well as the mean of the four series.

In the Oquawka field the recovery of organic matter is fairly consistent for three of the four series used. The high value, 25%, in series 500 is not accounted for. In the Lebanon field the average recovery is practically the same as in the Oquawka field. The high percentage recovery in series 400 may be due in this case to known soil conditions. On page 152 of Illinois Agricultural Experiment Station Bulletin 273 occurs the following statement concerning this field: "The field is thoroly tiled and drains well except in the lower portions along the east and south." Series 400 occupies the southeast portion of this field, which does not drain well, and possibly the deficiency in aeration has retarded oxidation of the organic residues. On both the Oblong and Clayton fields, especially the latter, the results are more erratic. On both of these fields the apparent retention of organic matter is very high in series 300. No satisfactory reason for this is apparent. Series 300 of both fields was in oats stubble at the time of sampling, having had cornstalks returned to these plats in the preceding spring. On the Clayton field the surface slopes

TABLE 2.—*Crop residues added to the soil and percentage retained in soil organic matter.*

Field and period of experimental cropping previous to sampling	Series	Approximate amount of residues added in pounds air-dry material per acre	Percentage excess of organic carbon in residue plat over check	Equivalent in organic matter in pounds per acre	Percentage of residue retained
Oquawka, 14 years	200	7,600	0.038	1,310	17.2
	400	11,000	0.054	1,860	16.9
	500	6,500	0.047	1,620	25.0
	600	3,900	0.017	585	15.4
	Mean	7,250	——	——	18.5
Lebanon, 12 years	100	21,280	0.110	3,790	17.8
	200	14,840	0.048	1,660	11.2
	300	16,740	0.056	1,930	11.5
	400	19,920	0.186	6,400	32.1
	Mean	18,195	——	——	18.2
Oblong, 13 years	100	9,390	0.033	1,138	12.12
	200	13,040	0.040	1,379	10.58
	300	10.870	0.125	4,310	39.65
	400	12,370	0.080	2,758	22.29
	Mean	11,417	——	——	21.16
Clayton, 15 years	100	22,120	0.086	2,965	13.40
	200	21,470	0.022	759	3.54
	300	19,190	0.183	6,310	32.88
	400	20,600	0.047	1.621	7.87
	Mean	20,845	——	——	14.42

from plat 305 to plat 306 on a grade of approximately 1.5% and this might allow slight surface washing. Mooers[3] studied the organic matter retention in a similar way in an experiment field at Knoxville, Tennessee, and reports 6.5% recovery of organic matter from the turning under of 20 green cowpea crops over a period of 20 years.

In connection with this discussion the fact should not be overlooked that the mere piling up in the soil of organic materials is not necessarily desirable. It is much more to be desired that frequent replenishment be made of materials which will readily decompose, furnishing energy for the micro-flora of the soil with its attendant benefits. Furthermore, the kind of organic materials added is of much importance. It has been demonstrated by numerous investigators that a high proportion of nitrogen to carbohydrate favors nitrate formation and accumulation, while a high proportion of cellulose or other carbohydrates either induces more rapid growth of nitrate-consuming organisms, or retards the activity of the nitrifiers, thus preventing nitrate accumulation.

EFFECT OF RESIDUES UPON CROP YIELDS

It may be of interest to note the effects upon crop yields of the crop residues returned to the soil. For this purpose the summarized yields and their increases are brought together in Table 3. Significant crop increases, as indicated by Student's method, occur on more fields than was found to be the case with organic-matter increases in the soil. Corn responded to a significant extent on five of the seven fields, including three of the four fields showing gains in organic carbon. Oats responded on only two of the four fields on which they were grown, namely, Oblong and the Davenport plats; while wheat responded to residues on four fields, including three which gained in organic carbon content. It is not surprising that the plats showing the largest gains in organic matter are not always the ones producing the largest gains in crop yields. So far as the organic matter factor affects crop yields, it is that portion which decomposes in the soil, and which therefore cannot be found in the chemical analysis, which is most effective, rather than that which remains.

A lack of parallelism exists, not only between crop yields and organic matter gains, but also between crop yields and total soil organic matter. This is illustrated by the results on the experiment fields used in this study. Using the check plats for the comparison, it is seen from Fig. 2 that, while in general the soils high in organic matter are better for corn production than those which are low, the relation-

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[3] Tenn. Agr. Exp. Sta. Bul. No. 135, May 1926.

TABLE 3.—*Crop yields and increases for residues with odds computed by Student's method, Illinois fields, in bushels per acre.*

	Oquawka	Palestine	Lebanon	Odin	Oblong	Clayton	Davenport plats
			Corn				
Untreated yield...	16.8	17.6	25.9	22.6	19.2	35.4	51.1
Gain for residues..	2.8	2.9	4.3	0.8	5.9	10.7	2.0
Number of crops....	8.0	5.0	10.0	22.0	12.0	13.0	27.0
Odds.	14:1	49:1	85:1	4:1	493:1	>5000:1	236:1
			Oats				
Untreated yield....	—	—	29.2	—	15.9	38.6	50.8
Gain for residues	—	—	3.4	—	6.5	3.1	2.4
Number of crops....	—	—	7.0	—	10.0	13.0	26.0
Odds.............	—	—	6.1	—	278:1	10:1	102:1
			Wheat				
Untreated yield	10.2	10.1	25.1	10.5	8.8	17.4	25.7
Gain for residues...	1.9	0.1	1.9	−0.3	3.0	3.0	2.8
Number of crops....	7.0	5 0	9.0	20.0	11.0	12.0	19.0
Odds.....	46:1	<1:1	7:1	2:1	219:1	179:1	122:1

TABLE 4.—*Organic carbon, nitrate production, and corn yields on the Morrow plats.*

Plat	Cropping system	Soil treatment	Organic carbon in soil 0–7 inches		N changed to nitrate in pounds per acre[a]	Corn yield in bushels per acre
			1913 %	1923 %		
3 N	Continuous corn	None	2.08	1.94	64	24.1
4 N	Corn, oats	None	2.36	2.21	96	35.9
5 N	Corn, oats, clover	None	2.63	2.57	160	55.5.
3 S	Continuous corn	Manure, limestone, phosphate	2.48	2.35	193	41.4
4 S	Corn, oats	Manure, limestone, phosphate	2.63	2.68	300	59.6
5 S	Corn, oats, clover	Manure, limestone, phosphate	2.92	2.87	289	70.7

[a] Nitrate-nitrogen produced in four weeks with ammonium sulfate added.

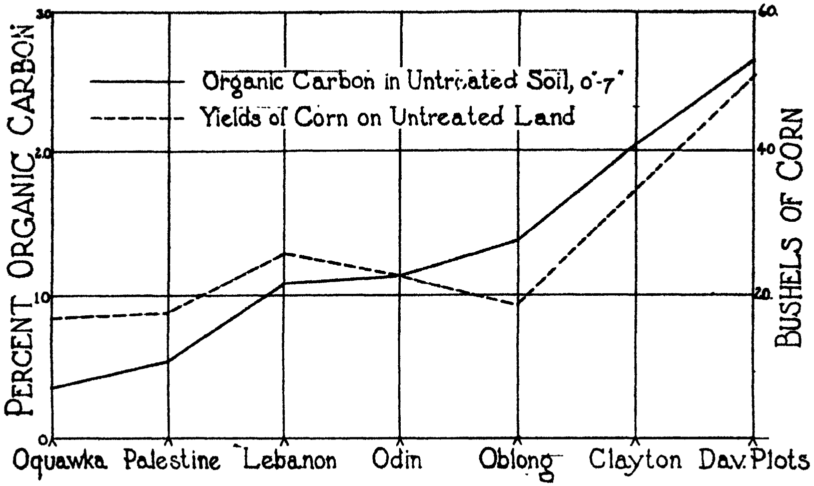

FIG. 2.—Soil Organic carbon in relation to corn yields on some Illinois experiment fields.

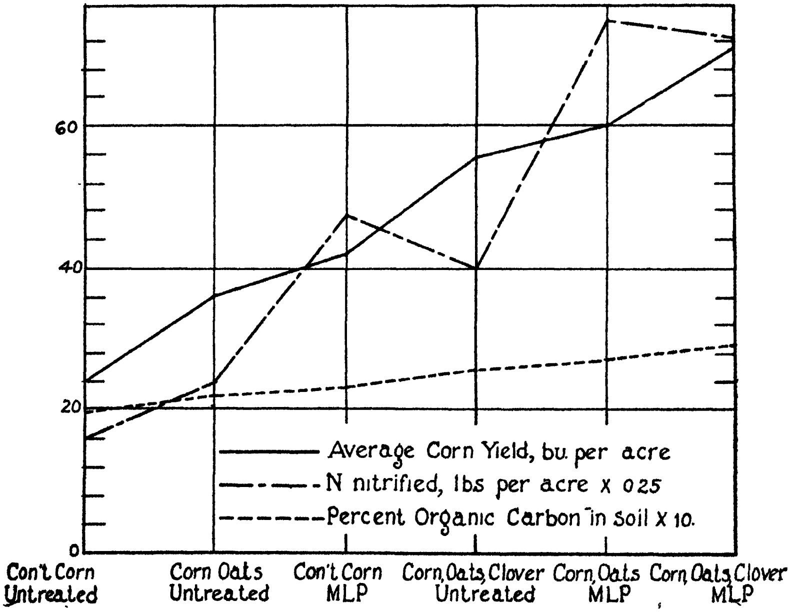

FIG. 3.—Relation between soil organic carbon content, nitrifying power, and corn yields, Morrow plats, Urbana.

ship is by no means wholly consistent. Thus, for example, the corn yields on the untreated soil at Oquawka and Odin are nearly equal, averaging 16.8 bushels and 19.2 bushels, respectively. The organic carbon content of the latter field, however, is more than four times as high as that in the former. These respective values are 0.326% and 1.39% in the two fields. It is obvious from these data that other factors are more important than total organic matter in determining crop-producing power.

A sidelight upon the relation of soil organic matter and its transformations to yielding power is furnished by studies previously made upon the soil of the Morrow plats at Urbana. For the present purpose the plats may be considered as six in number, representing three cropping systems. These are continuous corn, corn and oats in rotation, and corn, oats, and clover in rotation. Each is carried out on untreated soil and on soil treated with limestone, phosphate, and farm manure. Organic carbon determinations on samples taken in 1913 and in 1923 are reported in Table 4, together with the results of a nitrification study on the 1923 samples and the corn yields from 1904 to 1924, inclusive, for those years in which all the plats grew corn at the same time.[4] The data are shown graphically in Fig. 3.

It will be noted that in 1923 the organic carbon content of the soil under the best management (plats 4S and 5S) was approximately 50% higher than that of the untreated continuous corn plat, while the nitrifying capacity was nearly five times as high. The corn yields, following the nitrate curve more closely than the organic carbon curve, are nearly three times as high in the three-year rotation with treatment as on the land under continuous corn with no treatment. These considerations lead to the conclusion that, while the return of organic residues has not caused the accumulation of large amounts of organic matter, such practice has, nevertheless, added a large amount of organic material. This material has largely decomposed from year to year as added, with attendant benefits to the crops produced.

GENERAL CONCLUSIONS

Based upon the material presented in the foregoing pages, it is believed that the following conclusions are warranted:

1. The variability of field soils makes the problem of determining increases in organic matter brought about by treatment a difficult one, requiring great care in selecting similar pairs of plats for comparison.

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[4] The author is indebted to Prof. O. H. Sears who supplied the data on nitrification.

2. Nonlegume crop residues, including cornstalks and the straw of small grains, decompose fairly rapidly when incorporated in well-drained soils, leaving but a small residuum of inert material to add to the total stock of soil organic matter. This accumulation slowly reaches measureable proportions, the time required depending upon factors not determined.

3. The increases in crop yields resulting from the addition of crop residues are probably due largely to the benefits attending the decomposition of active organic matter rather than to the mass of residual organic matter persisting in the soil.

3. ORGANIC MATTER REQUIREMENTS OF SOILS UNDER VARIOUS CLIMATIC CONDITIONS[1]

J. C. Russel[2]

It is commonly considered that soils require organic matter, which may or may not be the case. If they do, it is pertinent to ask what quantities are required, and what principles should be followed in supplying them under various climatic conditions. If they do not require it under some conditions but do under others, it is pertinent to ask if climate is one of the determining factors, and why. If organic matter is not required at all, the fact is not yet proved and would be the only thing left for discussion under the title that the leader of this symposium has suggested for this paper.

The writer proposes to assume that organic matter is a soil requirement under some climatic conditions and will attempt to explain why and to what extent it is, and will discuss certain relations of organic matter content of soils to climatic factors and the bearing of these relations on the practice of restoring or maintaining organic matter as a useful, if not always a necessary, constituent.

Thorne (18)[3] recently has reviewed the results of long-time plat experiments in this country and England with consideration of the question of the comparative value of barnyard manure and chemical fertilizers and has concluded that, from the standpoint of increasing yields, manure is not superior to chemical fertilizers furnishing the same quantities of essential elements. In other words, its organic portion has no value aside from furnishing nitrogen.

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[1] Paper read as a part of a symposium on "Soil Organic Matter" at the meeting of the Society held in Washington, D. C., November 19, 1926. Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebraska. Published with the approval of the Director, as Paper No. 38. Journal Series.

[2] Agronomist.

[3] Reference by number is to "Literature Cited," p. 388.

In the Missouri experiments (9) manure and chemicals on wheat continuously have increased yields to an equal extent throughout a 30-year period. Analysis of the top foot of soil after 25 years, however, has shown no more nitrogen in the chemically treated than in the untreated soil, but about 30% more where manure had been used.

Obviously, in such cases the question of organic matter being a soil requirement is purely one of the economics of substitution. In humid sections generally home production of organic matter to furnish nitrogen and unlock the chemical reserves in the soil and chemical fertilization are both possible and practical, and the question as to which should be done would seem to be solely one of comparative net profit to be settled on the basis of acre yields and production costs. On heavy soil types of refractory tilth or on sands which are inclined to blow and on fields which have a tendency to wash, the labor of tillage and the loss of soil by erosion are details which should certainly be taken into consideration, but which are not completely reflected in a statement of yield per acre.

In subhumid and semi-arid sections fertilizers are not a satisfactory substitute for soil organic matter. Where rains come spasmodically during the growing season, as they do in Nebraska, with fitful stages of drought at periods when corn and wheat are approaching maturity, the application of fertilizers in quantity is more apt to be depressive than beneficial. Early in the season they almost invariably accelerate growth. However, the demand for soil water is also increased, and when drought comes the fertilized crop suffers first and may be severely damaged before rains come, while unfertilized crops, having less leaf area, are able to tide over the dry period and may eventually yield well.

Up to the present time no method has been found of making the soils of subhumid and semi-arid sections as generally productive as they were a few years after they were first brought under cultivation, aside from irrigation and the practices possible under it. Occasionally, a farmer claims that his soil after years of cultivation is better than it was when new, but in such cases the land was either inferior in the beginning for some extraordinary reason, or occupies an especially favorable position with respect to moisture, or some other factor is involved. The organic matter of new soil after the tough grass roots have partially decayed is an ideal soil constituent. When the soil is warm and moist and plants are growing rapidly, nitrates are elaborated rapidly, but not excessively, and the plants thrive. As the soil becomes dry and the plants begin to suffer, nitrification diminishes also, and thus the plants are automatically saved from excessive nutriment in time of drought. In addition, the structure of new soil facilitates intake of moisture and reduces run-off, prevents baking and cracking and excessive evaporation from the surface, and the fibre in it helps to prevent erosion by water and wind. Also, if observations are correct, the draft of implements is less, the quality of the tilth is better, and less labor is required to achieve the ends of tillage.

The hope of the farmer and the ambition of the soil investigator is to discover a method of restoring to the soil its virgin productivity. Soil analysis may reveal that organic matter and nitrogen have suffered extensive loss, and other studies may show that the nitrification and carbon dioxide production rates have declined, that the soil has become tougher and harder and cracks worse, and that it does not scour as well as formerly. The obvious correlation of loss of organic matter with the progressive development of these conditions has suggested to all that organic matter be restored in quantity. Is this correct? Because two things are correlated, are they cause and effect? May it not be that the important thing is to restore a soil condition and not any particular quantity of substance?

If quantity of organic matter is the desideratum, the prospect of restoring or even maintaining it at any relatively high level is very gloomy for the subhumid and semi-arid farmer. The use of barnyard manure and legumes is not completely practical. Along the outer borders of subhumid areas, manure may be used with profit if it is not used too heavily, otherwise it "burns" the crops. Sweet clover can be grown with safety and is profitable, but occasionally a crop "burns up" on sweet clover land. This was the case with corn in eastern Nebraska this year. Alfalfa is grown widely and no one hesitates to plant it, but all hesitate to plow it up because the subsequent crops so frequently suffer. Within the subhumid, and particularly within the semi-arid area, the use of either manure or legumes is precarious. The writer saw one field in central Nebraska recently that had been in alfalfa and after it was plowed up seven successive grain crops had been lost on it, while crops on adjacent land that had not been in alfalfa had yielded well. This is a fairly typical case.

The explanation of these effects is that too much nutriment is made available from the rapid decay that occurs with such materials and over-stimulation results just as with commercial fertilizers. Lighter quantities of manure and a shorter period of alfalfa growing in the rotation should alleviate the trouble. However, it is hard to convince the farmer that such practices would be economical for him to follow, if indeed they are.

More careful return of crop residues would seem to be a partial solution of the problem of restoring organic matter, although it has its disadvantages and unsound features. Trashy material in dry areas makes the soil open and loose and allows it to dry with excessive rapidity. Furthermore, wheat straw appears to repress nitrate production to a serious extent in some seasons. Sievers and Holtz (13) have pointed out that the practice of careful return of crop residues should be begun while the soil is yet new and able to overcome their repressive effect by its own high nitrification rate.

The possibility of azofication saving the day for the semi-arid farmer must be taken into consideration. Gainey (3) is of the opinion that methods may be found to intensify the activities of the azofiers and make them a factor of consequence in maintaining the nitrogen balance in western Kansas.

If a soil condition rather than a definite quantity of organic matter is the thing to be restored and maintained, methods have yet to be evolved. The condition which exists in new soil is a mechanical product, produced by the interlacing and clutching of earth by myriads of roots, and compression of earth into granules whose identity, stability, and permanence are established by a surrounding colloidal film of humified root material. In devising methods to restore this condition it may be wise to keep nature's method in mind.

Whether organic matter is a soil requirement or not, the application of barnyard manure and crop residues and the growing of legumes will prevail. Farmers will always be interested in maintaining organic content and agronomists will be concerned in the science and practice of doing it. Of the various questions involved the one which is most closely related to the subject of this paper is the quantity which may be recommended for different kinds of soil under various climatic conditions.

Hilgard (4) in 1911 wrote that it was remarkable "the unanimity with which about one-tenth of one percent (of nitrogen) has been assumed as the ordinarily adequate percentage." This much nitrogen is equivalent to about 2% of organic matter. Mosier (10) once stated that a "good productive soil should contain from 4 to 10 percent of organic matter." The wide variation in the organic matter content of soils the country over and the comparative adequacy of a small percentage in one soil and the inadequacy of a larger percentage in another should lead us to question the soundness of advising any one quantity for all soils, and would suggest that we search for the explanation of the variations which occur and learn to use them as bases for local recommendations.

Texture appears to be the most important factor determining organic content. That there is a general relationship of organic content to texture is commonly accepted, but that this relationship may be a very intimate one is not so well understood. As early as 1918 the writer, working with Dr. F. J. Alway, observed that the nitrogen content of a series of 0–6 inch soil samples taken from one Minnesota county (11) varied quite closely with their texture when the latter was expressed by some single numerical constant like the hygroscopic coefficient or moisture equivalent. Since then, numerous virgin prairie samples have been taken to depths of 6 and 12 inches in Kansas, Nebraska, and Minnesota, and the correlation further investigated. It has been found (7) that the nitrogen contents of surface samples taken to a uniform depth from any area of virgin prairie soil which is ecologically established bear a remarkably constant relation to the hygroscopic coefficient, even though the area contains soil textures ranging from heavy clays to coarse sands. The ratio of hygroscopic coefficient to nitrogen, which is usually between 30 and 50:1 in soils which we have examined, is so constant that when it has been established for any one soil series the nitrogen content can be estimated from the hygroscopic coefficient to an accuracy of about 5% of the total nitrogen present.

If this correlation be found to hold generally, it will mean that texture is a factor to be taken into consideration in all investigations of comparative organic contents, precisely as it is done in most all soil moisture studies. Apparently this has never been done, the only approach to it being in the work of Sievers and Holtz (13) in Washington.

Rainfall is another factor that affects organic matter content. Sievers and Holtz (13) have pointed out that the organic matter content in fine-textured Washington soils under 20 inches or more of rainfall may be over four times as much as in similar textured soils under 8 inches of rainfall. Other things being comparable, virgin western Nebraska soils under 16 inches of rainfall contain only 58% as much organic matter as eastern Nebraska soils of corresponding texture under 30 inches of rainfall.

Organic matter content in virgin soils is probably also correlated with latitude, that is with temperature, length of growing season, and all of the other factors of climate commonly associated in this country with latitudinal lines. Just what the relation may be we are unable to state for our studies so far have extended only from southern Kansas to central western Minnesota. However, indications are that ecologically established virgin soils in northern regions may contain more organic matter than in southern.

There are possibly other correlations. It would be exceedingly interesting to know what the effect of high acidity or high lime content actually is, or what response is made to wide variations in phosphorus or potassium. It is generally believed that a high lime content leads to increased organic matter content under virgin conditions. At least calcarious soils are usually blacker (8). Until we take texture and climate into consideration in our comparisons, we may never know accurately what effect lime has.

The writer is aware that conclusions based on data from a limited area of prairie country may not be valid elsewhere. Indeed, in the prairies the relations of organic matter to texture and climate hold only on virgin soils which are ecologically established, that is, on soils in which the present virgin cover has been in existence for a long time and where processes of erosion or construction are not operating faster than processes of organic matter production. However, the fact that correlations exist at all in any soil is interesting and demands explanation. And it may be that a proper explanation will furnish a clue to a more scientific consideration of the problem of organic matter requirements in cultivated soils.

In the production of organic matter in soils two processes are involved, the production of organic material by plants and its decay by soil organisms. Soil organic matter itself is only the mixture of partially decayed and undecayed material (and soil organisms) which the chemist finds on analysis. These two processes are not independent, each depends on the other to an extent. If under well-drained conditions much organic material be produced and if it is returned, decay will be accelerated, but if little be returned, decay will be slow. What we have called an ecologically established virgin soil is supporting all of the plant and micro-organic life that it is capable of supporting under the climatic and soil conditions that obtain. It will support more of both only when that factor which is the limiting factor is removed. Under such conditions production of organic-matter-forming material balances decay, and the mixture known as soil organic matter is maintained at a constant quantity. It is also maintained as a constant composition by balances among the micro-organisms of the soil in a manner that Waksman (19) has well explained.

All factors which affect life on and in the soil combine to determine the equilibrium point in organic matter content. Texture is important on the one hand because it affects plant production through its relation to the soil moisture and nutrient supply. On the other hand, it is important because it affects the processes of decay through its influence on aeration. However, texture may be most important as a factor in retaining organic matter against loss by leaching. Moisture is the most important factor in plant production in most sections, and variations in organic content with rainfall follow logically. Going from deficient into adequate areas of moisture, however, may not increase micro-organic activities as rapidly as plant production, hence organic content would increase relatively rapidly until that precipitation zone had been reached where other factors begin to limit plant growth. Then processes of decay would gain relatively on plant production and organic content would not seem to increase so rapidly with rainfall. It would be interesting to carry the explanation further into zones of excessive precipitation and leaching and also into zones where the moisture supply is so high that water-logging results and decay is retarded, but to do so would exceed the scope of present data. Temperature, which affects the rate of vital activities, and length of growing season, which determines their magnitude, and combinations of temperature, length of growing season, and the length of the season of suspended activities would be an interesting subject for speculation, but again no data are available against which one's reasoning may be checked.

Bringing soil under cultivation is, from the standpoint of the soil, a serious disturbance. Plants are removed more or less instead of being allowed to decay where they grew; temperature, moisture, and aeration relations are altered; and all micro-organic life is thrown out of balance. Under cultural conditions decay may, and usually does, out-run accumulative processes. Ladd (6), Snyder (14), Whitson (20), Alway (1), Conner (2), Swanson and Latshaw (16) in the central region; Thatcher (17), Jones and Yates (5), and Sievers and Holtz (13) in the northwest; and Shutt (12) in Canada have all observed large losses of organic matter and nitrogen in soils only 20 to 60 years removed from the virgin condition, and a number of these investigators have noted in particular that the losses were decidedly out of proportion to the nitrogen used by the crop.

Occasionally the hand of man disturbs the soil to its advantage. Stewart (15) in Utah found that continued growing of wheat under dry land conditions apparently increased organic content slightly, and Sievers and Holtz (13) state that it is not unusual to find in western irrigated sections that soils are growing richer in organic matter with cropping instead of poorer, as a result of the increased moisture. Shutt (12) has suggested that the decline in nitrogen and organic matter is most rapid in the earlier years of cultivation and later on becomes negligibly slow. Alway (1) 15 years ago showed that Nebraska soils which had been farmed 30 years had lost 30% of their organic matter, or 1% per year. Studies similar to his made today show that soils that have been under cultivation 45 years have not lost 45% of their organic matter, but less than 40%. This decline in the rate of loss is logical and eventually the organic content of our soils may be reduced to that base level at which nitrogen is lost only as rapidly as crops remove it.

It would seem to follow from the ideas developed above that man will find it relatively uneconomical, if not impossible, to put into soil any more organic matter than nature put there under virgin conditions, except as he may do so after having first modified the actual conditions that originally obtained. To an Iowan who may move from an area of almost jet-black Webster loam to a very light brown Rosebud loam of extreme southwest Nebraska, it may occur that the problem of soil moisture which he there faces can be alleviated by building up in his soil a considerably higher organic content. Can this be done? Experience shows that it cannot and that he who tries it courts disaster. In the Sand Hill section of Nebraska we have a soil sparsely covered with natural grass vegetation. Curiously this soil has just as much organic matter and nitrogen in proportion to its hygroscopic coefficient of 2.5 as eastern Nebraska silt loams with their hygroscopic coefficients of over 10. On account of its extremely low water-holding capacity crop production is seriously curtailed. In the virgin condition it contained about 1.5% of organic matter which all may agree is not enough. We wish that it had 6%, for then its water-holding capacity would be increased enough to be of considerable significance. Experience shows conclusively that we cannot put 6% of organic matter into this soil. Ordinary quantities of manure applied annually fail absolutely to increase the organic content beyond the virgin level. It would probably be more economical to haul clay on to such a soil to increase its water-holding capacity rather than to attempt it with barnyard manure.

In sections where manure is scarce and legumes are expensive to grow it would seem to be extravagant to attempt to maintain the organic matter content of a soil at a level close to that in virgin land or to build back run-down soil any further than to the point at which crops utilize most profitably all of the nitrogen supplied in the manures.

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4. SOIL ORGANIC MATTER AND MANURIAL TREATMENTS[1]

J. W. WHITE[2]

Chemical and biological studies of the residual effects on the soil of various manurial treatments are essential to the proper interpretation of field data with respect to the differences in response of field crops to fertilizer applications. In our more comprehensive field plat experiments, therefore, provisions are made for such studies, especially as related to the effects of the particular treatments on soil organic matter. A review of the literature concerning such studies shows that as the result of different conditions and methods of experimentation the investigators differ widely in their interpretations and subsequent recommendations. This is especially true in regard to the comparative effects of different liming materials on the decomposition of soil organic matter.

A brief review of the literature on this one phase of the subject under consideration serves to emphasize the different results secured.

In their studies on Rhode Island soils in 1899 Wheeler, Sargent, and Hartwell (18)[3] concluded that air-slaked lime caused an increase in organic matter on grass plats as compared to unlimed soils

Hess (6) in 1899 and 1900 studied the limed plats of the Pennsylvania field experiments and found less organic matter and nitrogen on the plats treated with caustic lime than on those that had received carbonate of lime.

Hartwell and Kellogg (5) in 1906 concluded from further studies at the Rhode Island Station that the effect of lime depended largely on soil reaction.

Mooers, Hampton, and Hunter (12) in 1912 reported a greater loss of nitrogen on limed plats than on those unlimed.

McIntire (11) from a study of the Pennsylvania plats in 1911 concluded that caustic lime caused a decrease in organic matter as compared to carbonate of lime.

Lipman and Blair (8) in 1913 reported a greater loss of nitrogen on limed land than on unlimed soil.

Potter and Snyder (13) reported in 1916 a gain of nitrogen as the result of liming.

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[1] Paper read as a part of the symposium on "Soil Organic Matter" at the meeting of the Society held in Washington, D. C., November 19, 1926. Contribution from the Department of Agronomy, Pennsylvania State College, State College, Pa.

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[3] Reference by number is to "Literature Cited," p. 395

Bear (2) in his studies of Dekalb soil at the West Virginia Experiment Station in 1916 concluded that quick lime caused a loss of organic carbon and nitrogen.

In 1922, Carlson (3) from his studies concluded that in general the limed plats contained more organic carbon and nitrogen than did the unlimed plats.

Hess (6) in his studies of the Pennsylvania plats in 1899 found in the limestone treated soil 0.2% organic carbon and 0.0169% nitrogen in excess of that present in the soil treated with caustic lime. Hopkins (7) from these data computed that the effect of caustic lime as compared with limestone was equivalent to the destruction (in terms of the nitrogen difference of less than 0.02%) of 37½ tons of farm manure in 16 years, or equivalent to the liberation of more than $7.00 worth of nitrogen for every ton of caustic lime applied. In like manner the difference of 0.2% of organic carbon was computed to the equivalent loss of 37.6 tons of fresh manure in 16 years.

It is of interest to note that in computing the difference of 0.0169% nitrogen to the equivalent of pounds per acre Hopkins used as his weight per acre 9 inches of soil, 2,224,800 pounds as suggested by Hess. However, the carbon figures were computed on the basis of 2,700,000 pounds per acre.

In 1921, the writer (19) made a detailed study of the same plats as those examined by Hess and McIntire. As a result of this later study it was concluded:

(A) The odds, as determined by Student's method as discussed by Love and Brunson (10) and Love (9), indicate that the limestone and caustic lime treated plats are not significantly different in their content of organic carbon and nitrogen at the end of 40 years of continuous treatment.

(B) When the limed plats are compared with the untreated check plats in content of organic carbon, the caustic lime treatment only seems significantly higher than the untreated soil.

(C) In nitrogen content both the caustic lime and limestone treated soils are significantly higher than the untreated soil.

(D) The excess of organic carbon and nitrogen found on the limestone treated soil as reported by Hess and McIntire was shown to have been derived from charcoal discovered on the limestone plat of tier 4.

From a detailed study of the manure and lime and manure plats after 40 years of continuous treatment, the writer (20) concluded as follows:

(A) Lime has caused the decomposition in 40 years of 90% of the manure applied as compared to 84% where manure was used alone.

(B) It is estimated that 93% of the organic matter of the lime and manure plat is derived from crop residue compared to 88% where manure was used without lime.

(C) The lime and manure treatment showed a gain of 508 pounds per acre of nitrogen in excess of the untreated check soil compared to 214 pounds where manure was used without lime, resulting in a gain of 294 pounds in favor of the limed land.

(D) Lime has caused the decomposition of 2,900 pounds of organic matter in excess of the manure treatment, resulting in sufficient increased yields (13,120 pounds dry matter) of crops to leave a balance of 1,345 pounds of residual organic matter and 178 pounds of nitrogen.

(E) The excess of organic matter found on the unlimed manured soil as the result of earlier studies was due to the presence of charcoal discovered by the writer on plat 16, tier 2. On this plat it is estimated that 25% of the organic carbon is derived from charcoal residues.

In general, we may conclude that when used in connection with manure or a balanced mineral fertilizer the increased yields attending a normal lime application will furnish sufficient crop residue organic matter (roots and stubbles) at least to balance that lost as the result of increased bacterial activity and that there is no significant difference between the action of burnt lime and lime carbonate when applied in equivalent amounts of CaO.

COMPARATIVE RESIDUAL EFFECTS OF MANURE AND MINERAL FERTILIZERS

Independent of the nature of the fertilizing material used the ultimate residual organic matter content of a soil depends largely upon the cropping system. It is a well-known fact that soils in permanent grass invariably contain a higher proportion of organic matter and nitrogen than the same soil in a system of cultivation. Advantage of this fact is taken in the manner of planning grain rotations to alternate the periods of cultivation with a period in grass and leguminous crops. During this rest period there is a pronounced recuperative effect which under proper fertilization tends to balance the organic matter and nitrogen rapidly lost during the period of cultivation.

Snyder (16) has shown that continuous growth of wheat for eight years resulted in the loss of over 21% of the total nitrogen of the soil, equivalent to an annual loss of 175 pounds per acre in excess of that used as plant food. Shutt (14), Alway (1), Swanson (17), and others show similar results in relation to their field studies.

At the Pennsylvania Experiment Station[4] the division strips which divide the old fertilizer plats have been in continuous bluegrass since 1867. In 1922, the writer (21) made a study of the organic matter and nitrogen content of certain of these grass strips and at the same time made a similar study of the adjoining cultivated plats. It was found that after 55 years under the two systems the grass land soils contained, as an average, 16,299 pounds per acre of organic matter and 818 pounds nitrogen in excess of the six cultivated soils. Even where 6 tons of manure and lime had been used biennially for 40 years the untreated grass land soil contained 12,265 pounds of organic matter and 600 pounds nitrogen in excess of the cultivated soil. A comparison of the untreated cultivated check soil with that of the grass strips showed a gain for the latter of 20,168 pounds per acre of organic matter and 1,160 pounds nitrogen, or a percentage increase of 36.3 in organic matter and 46.9 in nitrogen content.

In the more depleted eastern soils the problem of soil rejuvenation through the systematic use of manure and mineral fertilizers in connection with different grain rotations has been the subject of careful investigation. In these experiments it has been found that the ultimate organic matter and nitrogen content of the soil reaches a more or less definite level in a particular soil in accordance with the nature of the cropping system. Attempts to increase and maintain an abnormally high organic matter content through the excessive applications of farm manure has met with failure and resulted in excessive loss of organic carbon and nitrogen.

Bear (2) concluded from his studies of Dekalb soil at the West Virginia Experiment Station that the organic matter of a depleted soil can be increased and maintained in a rotation system through the systematic use of mineral fertilizers without the return of crop residues other than the roots and stubbles. Also, that the nitrogen content of the soil in like manner can be increased and maintained without the use of mineral nitrogen or farm manure.

In 1924, the writer (21) made a study of the residual effects of mineral fertilizers on Dekalb soil at the Snow Shoe experiment fields, including plats in a four-year grain rotation and those similarly fertilized in permanent Kentucky bluegrass pasture. At the end of eight years of cropping it was found, as an average, that where mineral fertilizers were used the organic matter content of the soil in permanent bluegrass had increased 32.7% as compared to 18.4% in the cultivated soil. The bluegrass soil showed a gain of 33.3% in nitrogen as compared to 19.0% for the soil in grain rotation. From these data it will be seen that the rate of accumulation of organic matter under permanent bluegrass sod exceeds that of the cultivated soil by 78%.

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[4] These old plats were originally laid out in 1867 and from that time until 1881 were used for miscellaneous experiments. Since 1881 a definite field experiment has been conducted.

EFFECT OF MINERAL NITROGEN ON THE ULTIMATE DECAY OF SOIL ORGANIC MATTER

When crop residues of a low nitrogen content or a wide carbon-nitrogen ratio, such as roots and stubbles, are returned to the soil, the excess of carbon is utilized by soil organisms as a source of energy. Such action continues until the ratio of nitrogen to carbon is increased approaching a more or less constant ratio of 1:12.

Sievers and Holtz (15) found that the addition of nitrogen to straw, either in the organic or inorganic form, tends to reduce the excessive loss of carbon. In this connection they make the following statement: "Under conditions where organic matter of high carbon content is plowed under, as in the case of straw and heavy cereal stubbles, a treatment with a nitrogen fertilizer before plowing will not only overcome, in large part, the depressing influence on nitrate accumulation, but will also conserve much of the organic matter contained in the residue." It is of considerable interest to determine if this significant statement of Sievers and Holtz holds true under field conditions. If so, then plat soils which have received heavy applications of mineral nitrogen where the only source of organic matter has been derived from roots and stubble should show a higher organic matter content than plats treated with mineral fertilizers without nitrogen, especially when the total yields of dry matter have been less in the second instance.

A study of the old plats at the Pennsylvania Experiment Station after 40 years of continuous cropping shows that such is not the case. In fact, the three plats treated with nitrate of soda applied biennially to the corn and wheat ground show less residual organic matter than the average of the four plats which have received acid phosphate and muriate of potash. The same is also true of the three plats treated with sulfate of ammonia. In each case the nitrogen treated plats have received the same amounts of PK. The summary in Table 1 shows the total yields and residual organic matter at the end of 40 years on untreated check plats and those that have received complete fertilizers as compared to the PK plats.

TABLE 1.—*Yields and residual organic matter after 40 years continuous cropping on Pennsylvania Experiment Station plats, average of Tiers 1 and 3.*[a]

	PK, no N	Check, no N	Nitrate of soda, pounds of N			Sulfate of ammonia, pounds of N			Dried blood, pounds of N		
			24	48	72	24	48	72	24	48	72
Yields of dry matter.	100	63	109	113	115	102	99	91	102	109	113
Residual organic matter.	100	86	101	96	99	91	99	98	102	103	103

[a]Results expressed on basis of PK treatment as 100.

A study of Table 1 shows that nitrogen applied to the crop residues has not conserved organic matter, but, on the other hand, has apparently stimulated organic matter decay. If the total yield of dry matter produced in 40 years is divided by the pounds per acre of residual organic matter, we find that for each ton of dry matter produced on the PK plats there are left in the soil 717 pounds residual organic matter as compared to only 631 as an average for the nitrate of soda plats, 716 pounds for the sulfate of ammonia treatment, and 680 pounds on the plats treated with dried blood. From these figures it will be seen that the PK treatment shows a greater proportion of residual organic matter in relation to the total yield of dry matter.

It is of interest to study in a similar manner the effect of different amounts of nitrogen applied in ammonium salts on the conservation of soil organic matter in a system of continuous wheat culture as practiced on Broad Balk Field at Rothamsted. The summary in Table 2 shows the total yields of dry matter and residual organic matter at the end of 42 years (1852–1893) of continuous treatment as reported by Dyer (4), also the pounds per acre residual organic matter per ton of dry matter produced.

TABLE 2.—*Yields of dry matter and residual organic matter at the end of 42 years of continuous treatment on Broad Balk Field, Rothamsted.*[a]

	Mineral salts, no N	Check, no N	Full mineral and ammonium salts 43N	86N	129N
Yields dry matter.. ...	100	86	171	251	295
Residual organic matter[b]	100	95	109	118	122
Pounds per acre residual organic matter per ton of dry matter produced....	100	110	64	47	41
	858 lbs.	980 lbs.	565 lbs.	416 lbs.	366 lbs.

[a]Results expressed on basis of mineral treatment (without N) as 100.

[b]Computed from the organic carbon (C x 1.724) on basis of 2,592,621 pounds soil per acre 9 inches.

A study of Table 2 shows that the addition of nitrogen has greatly increased the yields of dry matter. If it is assumed that the increased yields have left in the soil the proportionate amounts of roots and stubble, then the effect of nitrogen has been to stimulate rather than retard organic decay. As an average, the three rates of nitrogen applications have caused an increased yield of 106% and only 17% increase in organic matter. For every ton of dry matter produced on the plat treated with minerals without nitrogen there is left in the soil 885 pounds per acre of residual organic matter as compared to only 449 pounds as an average for the nitrogen treated plats.

SUMMARY

From a brief review of the literature concerning the relation of manurial treatments to the maintenance of soil organic matter, it may be concluded that the evident differences of opinion among investigators is due to variations in methods and conditions of experimentation.

Where lime in its several forms has been used in connection with manure or a balanced mineral fertilizer, the temporary decrease in organic matter as the result of stimulated bacterial action is compensated by increased crop residues.

There is no measureable difference in the action of caustic lime and neutral carbonate on soil organic matter when applied in their equivalent neutralizing values.

Liberal use of mineral nitrogen as measured by long-time field experiments has stimulated the decay of organic matter in excess of such action by mineral fertilizer without nitrogen.

The laboratory observations of Sievers and Holtz concerning the effect of nitrogen on the conservation of organic matter is therefore not substantiated by long-time field experiments.

The economic importance of acid phosphate and potash used in connection with a grain rotation is emphasized by the fact that for 40 years without the use of applied nitrogen this treatment has maintained crop yields and soil organic matter. (Pennsylvania field plat experiments.)

The value of PK treatment in influencing the fixation of atmospheric nitrogen is shown from the fact that a total of 1,616 pounds of nitrogen have been removed by cropping on the Pennsylvania plats in 40 years and still the soil thus treated contains more residual nitrogen and organic matter than the plats treated with nitrate of soda or sulfate of ammonia.

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5. THE CHEMICAL COMPOSITION OF SOIL ORGANIC MATTER AS RELATED TO ITS EFFECTIVENESS[1]

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The great importance of soil organic matter in contributing to the proper physical condition and to the fertility of soils has long been recognized. In fact, organic matter has been the distinguishing characteristic between disintegrating rock and true soils. To contribute to its supply a great variety of plant and animal materials have been used. The chemical, enzymic, and biological processes resulting from such applications have attracted the attention of many workers. The earlier investigators adhered to the purely chemical explanation, assuming that the "soil organic matter" was formed by the action of atmospheric oxygen and of water. Later, it was shown that the soil contains micro-organisms capable of attacking the compounds present in the materials added to the soil, hence it was assumed that they probably play an active part in the formation of humus. But for all the theories advanced actual experimental evidence was lacking to explain the processes taking place. Every investigator, while contributing something to our knowledge of soil organic matter, has left us with little real understanding of the nature of this complex material in the soil.

As early as the beginning of the nineteenth century such men as Saussure (30),[3] Berzelies, Sprengel (40), and Mulder and Herman cited by Waksman (45) separated from the soil substances which were variously called ulmin, humin, humic, crenic, apocrenic, and geic acids and made a study of their properties. It is interesting to note that workers of today are re-discovering these same substances and have as yet added little to what was done by their predecessors.

The attention of the followers of these pioneers has been directed not to the soil organic matter as a whole, but to the study of those definite parts separated from the remainder by their solubility in alkalies or other solvents. The final result of much of this work is summarized by Schreiner and Shorey (33) who state that, "The most conspicuous feature of this work is the discordant results obtained for bodies bearing the same name and often obtained from the same source." The chemical composition assigned to these substances depended to a great extent upon the laboratory procedure, such as the concentration of the alkali, time of extraction, and temperature.

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[3] Reference by number is to "Literature Cited," p. 407.

A little different interpretation of the nature of organic matter was made in 1909 and 1910 by Baumann and van Bemmelen as cited by Page (24). They considered the soil organic matter to be of a colloidal nature formed by such chemical processes as hydrolysis, dehydration, and oxidation. They did not believe it to be an acid, but found that it was capable of high absorptive power, retaining the bases of salts and setting free the acids, these latter contributing to soil acidity.

While some workers were endeavoring to ascertain the constitution of certain fractions of the soil organic matter, others studied the effects of these substances upon the fertility of the soil or crop response. Hilgard (16), Alway (1), Lipman (21), and others studied the humus content of numerous soils and tried to relate it to the fertility. From their efforts no important deductions could be made.

Thus it is that up to the present time we know very little as to the true nature of soil organic matter. Schreiner and Shorey (33) have shown us that it is not a single compound, such as humic acid, or a group of compounds, but that it is composed of many different and unrelated substances. They have isolated and identified 20 compounds belonging to 9 different chemical groups. From their acid filtrate, corresponding to the so-called crenic and apocrenic acids, they obtained dihydroxystearic acid, picoline carboxylic acid, xanthine, hypoxanthine, cytosine, histidine, arginine, and pentosan. Their precipitate from the acidified alkaline extract corresponded to the humic and ulmic acids. From it they obtained resin acids, resin esters, glycerides, paraffinic acid, ligniceric acid, agroceric acid, agrosterol, and phytosterol. These results, they say, point to the great complexity of the organic matter and show why it is that earlier workers obtained such diverse results.

In contrast to the ideas of Schreiner and Shorey, Oden (23) claims that the organic matter is made up of a few definite chemical compounds, classified on the basis of their solubility in alkalies, water, and alcohol into humic, humic acid, ulmic and hymetomelanic acids, and fulvic acid. He shows that his humic acid group gives true salts with alkalies and possesses electrolytic conductivity. Hence, it appears to be a true acid, probably tri- or tetra-basic. With metals other than the alkalies it forms insoluble colloids, showing its relation to the colloidal electrolytes. His humic acid is supposed to have a definite chemical composition free from nitrogen, yet as isolated by

Oden's method it always contains some nitrogen. This, Oden claims, is present as an impurity. He considers humin as an anhydride of humic acid and that humic acid and hymetomelanic and fulvic acids are successive stages in the decomposition of humin.

Schmuck (36), in his later work, does not agree with Oden on the nature of humic acid. He says that chemically it is a nitrogen-containing substance of an acid type. This acidity is due to absorption processes and to the presence of the carboxyl groups. The salts which it forms he does not consider to be true salts, but complicated chemical and absorption compounds. He also thinks that humic acid contains the benzene ring giving it an unsaturated character shown by its easy combination with halogens.

It was difficult for the earlier workers to agree as to the form of nitrogen in the soil organic matter. Hermann and Mulder believed that the humic bodies absorbed free nitrogen from the air, often showing 4.5 to 11.6%. Detmer, and later Oden, concluded that the humic acid group only contains nitrogen as an impurity, while humin and other groups may contain it in complex forms. Schmuck considers it present in humic acid in an albuminoid form, since upon ignition the ash of humic acid is essentially that of albumin. The fact that the soil humic bodies may be protein in nature has recently been shown by Jodidi (20), Fischer cited by Wakswan (45), Potter and Snyder (28), and others. They have found soil nitrogen in the form of ammonia, nitrates, mono- and di-amino acids, acid amides, and other derivatives of protein decomposition. Part of the nitrogen, according to Süchting cited by Waksman (45), may be in the form of heterocyclic compounds, such as pyridine derivatives, which are resistant to the action of micro-organisms and hence tend to furnish nitrogen to the plant rather slowly. That such forms of nitrogen actually do exist is shown by the separation of picoline carboxylic acid from the soil by Schreiner and Shorey.

From the foregoing statements it is readily seen that, while a great amount of effort has been made to ascertain the chemical composition of soil organic matter, no definite systematic knowledge concerning it is available today. Waksman (43) states that one reason for this lack of results is that there have been very few attempts to study "how" humus is formed. He suggests that we would arrive at a clearer understanding of the nature of soil organic matter if we should study the agencies acting, the substances involved, and the environmental influences. He points out the heterogeneity of the soil organic matter, showing that it roughly consists of (a) the constituents of plants and animals introduced into the soil and undergoing decay processes; (b) various intermediate products which have been formed by the action of soil micro-organisms and which may undergo further decomposition; (c) substances which resist decomposition and which may persist in the soil for a considerable time; and (d) a number of substances that have been synthesized by the numerous groups of micro-organisms and which may be either living or dead cells or cell derivatives. This would indicate that the soil organic matter is not in a static condition, but that it is constantly undergoing change approaching a condition of homogeneity or a state of equilibrium. This homogeneous mass is what is usually known as "humus." In my discussion of the effectiveness of the soil organic matter on the basis of its chemical composition the term "soil organic matter" will refer to the four groups of substances described above. The ultimate composition will be considered to be carbon, hydrogen, oxygen, nitrogen, and the mineral elements occurring in plant and animal bodies.

I have classified the various effects of soil organic matter which may be related to its chemical composition into nine groups. This classification is not at all rigid and some groups may be placed with others. These effects of soil organic matter are as follows.

1. ON THE SOLUBILITY OF INORGANIC SOIL CONSTITUENTS

One of the benefits frequently attributed to the addition of organic matter to the soil is that of increasing the solubility of the inorganic soil constituents. Jensen (19) in studying mottle-leaf of citrus trees in California noted that the amount of mottling was the reciprocal of the amount of humus in the soil. There also seemed to be greater improvement with humus produced from legume crops. In order to explain this he studied the solvent action of decomposing organic materials on the soil minerals. Various organic solvents obtained from decomposing legume hays, barley hay, and manure were applied to two soil types, a clay loam and a sandy loam. He found that the solubility of calcium, magnesium, iron, and phosphoric acid was measurably increased, especially that of calcium and magnesium. He considered this increased solubility due in part to the soluble organic compounds resulting from decomposition and in part to the action of the inorganic salts contained in the organic substances. Fleischer cited by Waksman (45) explains this action on the basis of the absorption of the bases of neutral salts by the humus colloids, thereby liberating the acid which in turn attacks the inorganic compounds. He found that considerable amounts of phosphate is rendered soluble when peat and rock phosphate are allowed to remain in contact for some time. Ames and Schollenberger (3) report greater amounts of phosphorus absorbed by young plants fertilized with organic nitrogen fertilizers than when receiving only mineral nitrogen.

2. ON THE ACTIVITIES OF SOIL MICRO-ORGANISMS

There is no doubt that the soil organic matter is a very important source of energy material for the growth of soil micro-organisms. Experimental evidence points to the fact that the chemical composition of this soil organic matter greatly influences the numbers and activity of soil organisms. Waksman and Starkey (47) in 1924 found that, while most organic materials serve to increase the number of micro-organisms, not all of them have the same influence. It appears that substances containing a large supply of nitrogen promote the greatest growth of all organisms. To prove this they supplied nitrate to soils treated with cellulose and obtained increased development of the organisms. Starkey (41), in studying the decomposition of organic matter, found that the composition greatly affected the rate. There also seemed to be some correlation between the rate and the nitrogen content, those substances containing the greater percentage of nitrogen undergoing the more rapid decomposition. With substances low in nitrogen, such as rye straw, the addition of nitrates greatly accelerated the rate, while it had no effect upon alfalfa meal. The complexity of the material also affected the process, as the simpler substances are capable of being attacked by many organisms, while the more complex are decomposed by relatively few due to the resistant compounds present. Anderson (4) shows that for cellulose decomposition the rate increases with the increase in available nitrogen until the latter is present in amounts sufficient for the maximum growth of the micro-organisms. In order to obtain some information as to the availability of the nitrogen in the soil organic matter for this process, he carried out several experiments using a number of the cleavage products of proteins. He found that after the proteins were hydrolized to the amino-acid stage their nitrogen was practically as available as ammonia.

Another problem that has received considerable study is that of the effect of organic compounds upon the nitrogen fixation and nitrification processes. Hutchinson (17) found that carbonaceous materials were favorable for the activity of Azotobacter. But he also mentions the occurrence of periods of adverse conditions following the introduction of highly carbonaceous substances. He concludes that during this time any nitrogen fixation is masked by the nitrogen assimilation of the micro-organisms attacking the cellulose. That this is probably true is also shown by Doryland (14). Fred and Davenport (15) give a report of their work to test the effect of organic nitrogen compounds upon the activity of nitrobacter. Many workers had concluded that such substances were injurious to these nitrate organisms, yet these two men found no evidence that these substances were harmful and in fact they seemed to benefit them rather than inhibit their action. Remy and Rosing also report a stimulating effect on the nitrifying process.

3. ON SOIL REACTION

For many years it was thought that soil acidity was due to the presence of complex organic acids of the nature of humic and ulmic acids. Baumann and Gully (24) endeavored to show that such acids do not exist and that acidity is due to selective absorption of cations by the humus colloid. Oden (23), on the other hand, demonstrated that humic acid is a true acid, yet it is so insoluble that it cannot appreciably affect the acidity of soils. In fact he regards humic acid as beneficial in that its calcium salt exerts an important buffer action by reacting with harmful soluble acids and liberating harmless insoluble humic acid. The so-called liberation of free acids by the addition of neutral salts to soils he attributes to the replacement of formerly absorbed inorganic acids, as phosphoric and sulfuric, produced from inorganic sources. There may also be such organic acids as acetic, propionic, malic, and others, but these probably would not accumulate to any extent in normal soils.

4. ON THE ABSORPTIVE POWERS OF THE SOIL

This subject has attracted much attention during the last decade. Outstanding characters in this field are Gedroiz and Hissink. Gedroiz cited by Page (25) attributes the absorptive power of soil to its humic bodies and to a greater extent to its complex alumino-silicate substances. Page (26) states that, "The absorptive and exchange powers of the soil are probably vested in the colloidal matter. This exists in a gel condition and is both mineral and organic in nature." Van Bemmelen, Baumann, and Gully have demonstrated the colloidal nature of soil organic matter and evidence produced by many workers would indicate that this colloidal organic matter is capable of absorbing bases such as ammonium, potassium, calcium, and magnesium, and under certain conditions some acid radicals. The actual mechanism of the process of exchange and absorption, whether physical or chemical, is not the province of this paper. The power of a soil to retain considerable quantities of various cations is extremely important in plant nutrition as well as in aiding in the control of the soil reaction. It is also undoubtedly the controlling factor in determining the concentration and composition of the soil solution.

That the colloidal nature of soil organic matter is also important in connection with the water-holding capacity of soils is shown by the work of Alway and Neller (2), Crump (12), and Page (24). Rothamsted figures show that a soil supplied with humus averaged 4.5% higher moisture content throughout the year over that in a soil lacking a good supply. This increased water-holding capacity is due to imbibition of water by the gel and also to the decrease in diameter of capillary spaces due to the swelling of the humus. Crump (12) reports finding a constant ratio between the water content of a soil and the humus content for any one type of soil.

5. ON THE SUPPLY OF AVAILABLE NITROGEN AND MINERAL NUTRIENTS

That the content of the soil organic matter may have a direct nutritional value has been known since the time of the humus theory. Averages of analyses of mineral soils show that of the total amount in soils approximately 95% of the nitrogen, 33% of the phosphorus, and appreciable amounts of the potassium, sulfur, and calcium are contained in the organic matter. In the usual fertile soil these amounts may be of sufficient magnitude to be of considerable consequence. In addition, a definite portion ot the organic nutrients will be utilized by micro-organisms in the soil in the process of decomposition and this amount will only become available as their bodies undergo decay.

The ordinary method by which the nitrogen of soil organic matter becomes available for crop needs is commonly known. The question now attracting attention is that of the use of such intermediate products of decomposition as urea, creatinine, ammonia, etc., by plants. While the nitrate form of nitrogen is commonly considered the best, there seems to be evidence that many plants can make use of other forms. Schreiner and Skinner (35) have found that the simple amino acids are readily available to green plants, and probably some of the simpler peptones and polypeptids can be used to some extent. Hutchinson and Miller (18), working with peas, were able to bring about the utilization of considerable amounts of urea and ammonia and possibly small amounts of other nitrogen forms. Experiments by several workers seem to indicate that possibly corn and some other common crops can utilize ammonium salts as well as nitrates.

For many years the quantity of phosphorus in organic form in the soil was thought to be rather insignificant. But after the perfection of methods by Potter and Benton (27), and later by Schollenberger (31), for distinguishing between organic and inorganic phosphorus, it was found that 30 to 40% of the total phosphorus frequently was in the organic matter. This amount, especially in many soils, may be of considerable importance. In consequence, the questions as to the nature of these organic forms of phosphorus and their availability arise. The former has been studied by Auten (5, 6), Shorey (38), and Potter and Benton (27). Shorey was able to isolate nucleic acid as a form of organic phosphorus, and Potter and Benton obtained pyrimidine nucleotides. Auten was unable to find any appreciable amounts of either of these substances in the soil organic matter. He concludes that organic phosphorus does not exist in soil in any considerable amount as nucleic acid, phytin, lecithin, or as pyrimidine nucleotides. He was unable to determine the nature of the phosphorus compounds, but suggests that probably they are complex condensation products of Beckley's hydroxymethyl furfural. From this compound the phosphorus must be liberated by oxidation or hydrolysis. This renders the organic form less available and thus it tends to accumulate, while the more available inorganic phosphorus is used by plants. There evidently is need for much more information concerning this problem.

Very recently the question has been raised by Thorne (42) as to whether the soil organic matter possesses any other value than that of supplying nitrogen and the mineral elements. He cites field experiments, comparing applications of manure and chemical fertilizers, from a number of experiment stations, including Indiana, Pennsylvania, Missouri, Ohio, and Rothamsted. He shows that chemicals have been just as effective in maintaining the yields as have manures. In fact, to equal the results of chemicals it has been necessary to reinforce the manure with phosphorus. When we consider that some of these comparisons have been running for as long as 70 years, it would seem that the necessity for any organic matter other than that left by plant residues is unnecessary. Thorne also points out that the greater residual effect often claimed for manures is explained fully on the basis of the larger applications of essential elements in the manure and their slowness of availability. Hence it is that he questions the advisability of sacrificing crops of legumes for soil improvement when they might give greater monetary returns by other means, and the equivalent plant food applied by chemical fertilizers.

6. ON THE REDUCTION OF THE NITRATE CONTENT OF SOILS

Many cases of the injurious effects of applications of straw and other highly carbonaceous materials to the soil have been observed. The poorer plant growth resulting seems to be accompanied by a lessening of the supply of available nitrogen. The results of numerous experiments show that as the organic materials are incorporated in the soil a wide carbon-nitrogen ratio results which renders the necessity of the micro-organisms utilizing the available nitrates in the soil for their metabolism. Scott (37) noted that there was a marked decrease in nitrates following an application of wheat straw. After a time nitrates began to accumulate slowly. If, however, ammonium sulfate were added, there was a rapid accumulation. His results are substantiated by the recent work of Martin (22). Wilson and Wilson (48), working with soil cultures to which they supplied residues of timothy and clover, found that nitrates disappeared rapidly to begin with, but in a short time began to accumulate in the clover culture. The timothy culture required a much longer time to reach the limit of nitrate depression. Collison and Conn (11), in studying the effect of straw on plant growth, obtained results similar to the other workers mentioned, but conclude that there is yet another cause for such early harmful effects on the plants. This they claim to be due to harmful chemical compounds produced from the decomposition of the straw. To test this possibility they examined the residues of several plants and found the toxic substances salicylic acid, dihydroxystearic acid, and occasionally vanillin.

7. ON THE PRESENCE OF TOXIC COMPOUNDS IN THE SOIL

Within the last 20 years much attention has been directed to the possibility of toxic organic compounds being derived from the soil organic matter. Schreiner and Shorey (32), working with a number of infertile soils, were able to separate several compounds which proved to be harmful to growing plants. They concluded, therefore, that the presence of these compounds was responsible for the unproductive conditions of the soils. Later work by other investigators, including Robbins, Robbins and Massey (29), and Davidson (13), has shown that, while toxic compounds may result from unfavorable conditions of drainage, aeration, or soil acidity, a correction of these factors will bring about the disappearance of the toxic substances. Robbins found that soil organisms under favorable conditions were able to destroy such substances as cumarin, vanillin, pyridine, and quinoline. Schreiner and Skinner (34) note that fertilizers seemed to decrease the harmful effects of such compounds. English investigators have been somewhat skeptical as to the influence of these substances.

8. ON GROWTH-PROMOTING ACCESSORY SUBSTANCES

The fact that the composition of soil organic matter might include some growth-promoting accessory substance, analogous to vitamines for animals, was brought into prominence by Bottomley (7) in England. He found that extracts from bacterized peat had a remarkable effect on the growth of some plants both in water cultures and in soils. He attributed this effect to the presence of some accessory substances which he called "auximones." In order to test the actual existence of such substances, Bottomley worked with *Lemna major*, a plant reproducing by budding, in order to avoid the use of seeds as these might bear auximones. In the soil these plants grew well, but in Detmer's and Knop's solutions they failed to grow satisfactorily unless some organic extracts were supplied. Clark (9) and Clark and Roller (10) have tested the results of Bottomley by using the same plants and solutions and find that the growth of *Lemna major* in mineral solutions depends upon the concentration of the salts and that no organic matter is needed. They conclude that auximones are not essential for growth and reproduction. They may prove stimulating, similar to bios in the reproduction of yeast.

9. ON THE CARBON-NITROGEN RATIO IN SOILS AND THE SUPPLY OF HUMUS

A study of the composition of soils soon reveals that there is a more or less constant relationship between the percentage of carbon and that of nitrogen. It seems that the amounts of these elements tend to stabilize at a proportion of 10 parts of carbon to 1 of nitrogen. Just why it is that an application of organic substances of a carbon-nitrogen ratio as high as 80 to 1 results in such a narrow ratio has been the cause of considerable study. A number of workers find that there is a close relationship between the carbon-nitrogen ratio of the organic materials added and the quantity of soil organic matter remaining in the soil. Brown and Allison (8), Sievers and Holtz (39), and Waksman (44, 45, 46) show that when highly carbonaceous materials are added to the soil the micro-organisms produce a loss of carbon until the ratio is narrowed to a point suitable for the metabolism of the organisms. This seems to be the stable ratio in the soil. If now we consider the addition of substances with a narrower ratio, it is readily seen that the suitable balance will be reached much sooner and that there will be less loss of carbon to the soil. This should result in an increased amount of carbon remaining in the soil in the form of synthesized organic compounds which contribute to the soil organic matter. In order to render the ratio narrower when such substances as straw, stover, or grasses are applied to soils, it may be desirable to add nitrogen-bearing materials with them. An investigation of this procedure and its effect upon the accumulation of soil organic matter is being carried out by the author and will be reported later.

CONCLUSIONS

In conclusion, it appears that a survey of the investigational work shows that we are still greatly in need of a better understanding of the nature of soil organic matter. Until such information is obtained the problems in relation to organic matter conservation and supply cannot be satisfactorily solved.

The above discussion indicates that in the light of present knowledge the soil organic matter, as affected by its chemical composition,

1. Increases the solubility of some inorganic soil constituents.
2. Increases the numbers of micro-organisms and hastens the rate of their activities, provided the carbon-nitrogen ratio is narrow. (Organic forms of nitrogen upon hydrolysis are readily available to organisms.)
3. Has a buffer action in the soil helping to regulate soil reaction.
4. Provides colloidal material which is an important factor in base absorption and exchange and also in determining the soil's water-holding capacity.
5. Directly supplies nitrogen and mineral elements. (The availability of these is a subject needing further study. That farm manures or other organic residues possess any value beyond that of supplying plant food elements has been questioned.)
6. May possess such a carbon-nitrogen ratio as to result in the depression of soil nitrates due to their assimilation by micro-organisms.
7. May include toxic compounds, although these are seldom a factor in well-managed soils.
8. Probably does not contain auximones.
9. May contain carbon and nitrogen in such a ratio as to favor or discourage the accumulation of humus.

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TIME OF CUTTING WHEAT AND OATS IN RELATION TO YIELD AND COMPOSITION[1]

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INTRODUCTION

Yield per acre and quality are the two most important considerations in crops harvested either for grain or for hay. After a crop is grown, harvest and other operations should be planned so as to secure the best balance between yield and quality. Based partly on inadequate experimental results, two ideas regarding time of harvest of grain crops have become fairly prevalent among growers. Cutting grain crops several days before maturity (a) improves the quality (b) without reducing the quantity appreciably, particularly when the grain passes through the curing process in the shock.

In the northern United States and in Canada it is a common practice to cut grain several days early to minimize or avoid the harmful effects of frost. Due to the protection offered by larger mass, bundle and shock grain is damaged by light frost somewhat less than standing grain of the same moisture content. If the harvested grain has time to dry out somewhat before the frost occurs, it has an additional advantage in escaping damage.

Where large fields must be harvested with limited facilities, the harvesting operations are started early enough so that the work is completed before the last is over-ripe.

Under conditions which make it desirable or necessary to cut grain before maturity, this could be done to better advantage if growers generally knew what results may be expected from cutting at fairly definite stages of development that can be described and easily ascertained. Better descriptions of the stages of maturity of grain at each of the stages that cuttings are made would aid considerably.

With the idea in mind of learning the effect of harvesting wheat and oats at several stages of development and curing them in the shock on the yield and quality of the grain, work was planned and carried out during the summer of 1925. The object was to learn particularly to what extent materials stored temporarily in the leaves and stems are moved along into the grain when the crops are cut at various stages of maturity and placed in shocks.

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REVIEW OF LITERATURE

It is known that nutrients are taken up very rapidly by plants in early growth and particularly from the time of jointing up to the time of full bloom. By the time the kernels or seeds are forming, most of the materials have already been taken up, elaborated, and stored temporarily in the stems and leaves ready to be moved to the more permanent storage organs.

Liebscher's results (19)[3] based on four experiments of his own and on the results of other workers preceding him brought out the following information regarding the taking up of nutrients from the soil. (A) During the first period of growth a rapid taking up of plant food occurs which amounts in percentage to about twice the dry matter built up. Nitrogen and potash are taken up rapidly at this stage. (B) At the jointing stage there is a still more rapid taking up of plant food which remains somewhat below twice the amount of dry matter in percentage. (C) At bloom the rate of taking up of nutrients still remains high and dry matter is being built up rapidly. (D) At past bloom the total amount of nutrients has reached about its maximum and the building up of dry matter proceeds at a rapid rate. After this time only small amounts of some nutrients are taken up and materials stored temporarily in leaves and stems are moved to the permanent storage organs. (E) At maturity the total amount of nutrients declines somewhat.

Snyder's (25) work showed that in the first 50 days of its growth, at which time the wheat plant was 18 inches high and within 15 days of heading, 86% of the nitrogen, 75% of the potassium, and 70% of the silica had been taken up.

Adorjan (1) confirmed previous results and showed that the wheat plant takes up the several nutrients from the soil at different times and at varying rates. The ash content of the plant is high in the early stages. There is a lowering of percentage but an increase in amount up to heading time. After that the percentage remains about constant, but the total amount increases slowly, the maximum being reached a few days previous to maturity. In early stages phosphates are only less necessary than nitrogen. From the time of jointing through the period of heading phosphates are taken up more rapidly than nitrogen and after heading only small additional amounts.

Nitrogen is taken up most rapidly from resumption of growth of winter wheat to jointing. During that period it increases in percentage three times as rapidly as dry matter. At the time of bloom

[3] Reference by number is to "Literature Cited," p. 438.

83% of the total nitrogen has been taken up and part of it stored temporarily in the vegetative organs. As the grain forms there is translocated to it from the leaves approximately 50% and from the stems approximately 40% of the nitrogen they contain. Therefore, during the time of grain filling scarcely more than 40% of the nitrogen needed is taken from the soil. Trowbridge, et al (30) confirmed these results for wheat.

Gericke (8) and others have shown that applying nitrogen to wheat at heading time results in grain of higher protein content. Later results by Gericke (9) appear to indicate that plants take up a larger supply of nutrients during early growth than they need to complete their life cycle. More work along this line appears to be necessary.

The results secured by Swanson (27) lead him to conclude that high protein wheat is possible only if the supply of nitrogen in the soil and available to the plant during the time of kernel formation is ample and carbohydrate synthesis is not unusually high.

Brenchley and Hall (4) found that during the filling in of the endosperm nitrogenous and non-nitrogenous materials are moved in at about the same ratio.

Thatcher (28, 29) found that the dry weight of wheat kernels increased rapidly during the last few days of growth. There was a reduction in the percentage of nitrogen in the grain during the first part of the period of kernel development and an increase during the latter part of the development period. Both the percentage and the total amount of nitrogen increased as the wheat approached maturity. Bailey (2) made observations on the wheat that Thatcher used in his investigations and found that the kernels increased in size up to the last three days before maturity with a corresponding increase in weight. Woodman and Engledow (31) report similar results.

Four days before wheat was dead ripe, when the grain contained 38.4% moisture, Kiesselbach (16) found the water-free kernel weight averaged as great as any time later and for practical purposes should be considered mature at that time.

Harlan (11), working with barley, found an increase in both percentage and total amount of nitrogen in the grain up to maturity. After the time the kernels averaged 42.8% moisture there was no further deposit of dry matter in them. In a later article Harlan (12) concludes that, since 42.8 is an average percentage, it does not represent exactly the minimum moisture content at which translocation can take place but very near it.

Kedzie (14), and later Olson (21), working with wheat, found a decrease in nitrogen percentage as the grain became mature. Keitt and Tarbox (15) report an increase in the percentage of nitrogen in the kernels of oats up to the milk stage and a rather rapid decrease in the percentage from then on to maturity.

It is to be noted here that a lowering of the percentage of nitrogen in the kernels as they approached maturity is the opposite of the results obtained from the majority of recent investigations with wheat and barley.

From these investigations it is clear that plants take up mineral nutrients very rapidly from the time they make marked increase in stature up to the time of full bloom. Up to the time of heading these materials are taken up at a more rapid rate than dry matter is laid down. From heading time to full bloom the rapid taking up of materials continues. Phosphorus in particular increases rapidly during the period and dry matter is laid down rapidly. The materials are elaborated and stored temporarily mainly in leaves and stems from whence considerable amounts are moved to the grain during the filling period.

Pericarp and germ formation, filling, and dessication follow each other in seed development as seen in the very rapid increase in length at first with a more gradual increase in width and weight.

The time and the rate of taking up of nutrients from the soil by unharvested plants, as well as their temporary storage and translocation to permanent storage organs, are fairly well known. How serious is the interruption to the movements of materials temporarily stored in the leaves and stems when grain is cut before it is mature? Some work has been done with the idea of securing an answer to the preceding question.

Briggs (5) harvested samples daily with full length of straw attached from the time the grain was in the milk to the time it was fully ripe and dried them in a well ventilated location. He found that there was an increase in kernel weight when the grain was left unthreshed as compared with removing it from spikes immediately after cutting. The increases in weight due to translocation of material from the straw were greatest for the cuttings made at the milk and dough stages.

In the same year McDowell (20) cut wheat at four stages, *viz.*, milk, dough, yellow ripe, and dead ripe, as he termed them. Parts of the samples harvested at each stage were subjected to treatments as follows: (a) Kernels removed at once from the spikes, (b)kernels left in the spikes cut from the straw, (c) kernels left in the spikes attached to all the straw, and (d) kernels left in the spikes with straw and roots attached. The roots were set in water. The material was kept in the laboratory after harvest. There were indications that the kernels in the milky stage increased in weight due to translocation of materials.

Saunders (22) marked spikes of even maturity and then made cuttings at three-day intervals from July 21 when the kernels were very small until August 15 when the grain was ripe. The samples with (a) 3 inches of straw attached, (b) half, (c) full length, and (d) full length straw and roots attached were cured in a laboratory at ordinary room temperature. Due to the rapid drying out, no translocation of materials from straw to grain was found. The percentage of protein decreased from July 21 to August 30 and then increased slightly. There was an increase in the amount of protein to August 6 and from then on the amounts remained practically uniform to maturity. From the results the following conclusions were formulated: Slight loss in yield would result in eastern Canada from harvesting wheat a week early. In parts of Canada where the summers are cooler than at Ottawa the harvesting could be done at a still earlier date, probably two weeks early. Mention is made that in parts of Canada where the summers are short harvesting grain early is the common practice.

Dunham (6) cut five varieties of wheat and four varieties of oats at green-neck, yellow-neck, and mature stages. Green-neck stage is described as when the glumes of the terminal spikelets had turned yellow and the straw of the neck, that portion immediately below the spike or panicle, was still green. For the yellow-neck stage the straw just below the spikes or panicles was yellow, but the stems and leaves below were still somewhat green. The material was dried in the laboratory at room temperature. Comparisons were made by weighing equal numbers of kernels.

As an average for all varieties, there was an increase in weight of 15.7% for the wheat and 25% for the oats in favor of harvesting at maturity rather than at the green-neck stage. An average increase in weight of 13.9% for the wheat and 24.5% for the oats was secured in favor of the yellow- over the green-neck stage. These results were confirmed the next year when the grains were cut at the different stages and cured in the shock.

The moisture content of ripening grain was observed by Olson (21) to bear an important relation to the translocation of materials from the straw to the endosperm. He observed that wheat kernels ceased to fill when the moisture content fell below 40%. This, together with the findings of Harlan (11, 12) and Sharp (23) that translocation to the kernels ceased when the moisture content fell below about 40%, probably explains why the grain did not increase in weight in some of the trials where the material was dried out with comparative rapidity. Sharp (23) found that the synthesis of protein ceased when the moisture content of the kernel reached about 35%.

Considerable data are available from work conducted in such a manner that there was less rapid drying out of the straw and grain. For the most part the grain was cured in shocks. One of the earliest trials was conducted by Bedford (3). He cut wheat at early milk, late milk, dough, and ripe stages. Wheat harvested a week early in the dough stage yielded as high as that cut at maturity. An increase in bushel weight for the grain harvested at maturity was indicated.

Shutt (24) harvested three lots of samples at intervals of from two to three days each. From one the kernels were removed immediately; from another the kernels were left in the spikes to which 6 inches of straw was left attached; and for the third the kernels were left in the spikes and full length of straw attached and cured in the field in shocks. The weights per 1,000 kernels averaged higher for the shock-cured grain than for the others to July 17 and after that the weights were practically the same for all three. The protein percentages for each of the three series decreased slightly and then increased up to July 8 after which changes were slight.

Kiesselbach (16) gives results for Turkey wheat harvested at three stages of maturity, *viz.*, (a) early dough, (b) late dough, and (c) ripe for a five-year period. The data are from duplicate field plats and the grain was cured in the shock.

In another experiment 10 systematically distributed quadrats of the same variety of wheat were harvested at the following stages: (a) Milk, (b) early dough, (c) medium dough, (d) stiff dough, and (e) ripe. The grain was cured in shocks in the field. These stages vary from two to four days apart.

In the first experiment there is little change in the protein percentage from early dough to maturity. However, there is a decided increase in yield and weight per bushel from the early dough to the late dough stage and slight increases thereafter. In the second experiment the increase in yield in the three-day period between the stiff dough and ripe stages is only 1 bushel, while between the medium and stiff dough stages the difference is 2 bushels. The 1,000-kernel weight for the stiff dough and ripe stages is practically equal.

Three-year average yields and weights per bushel are given by

Kiesselbach (17) for oats harvested at two-day intervals, beginning six days before maturity. The oats was considered mature when three-fourths of the panicles appeared fully ripe. Harvesting four days early did not lower the yield but resulted in a decrease in the weight per bushel.

Baking tests were made of wheat cut at soft dough, hard dough, and maturity by Guthrie and Norris (10). Cutting at the hard dough stage did not result in smaller loaf volume.

Harlan and Pope (13) come to the conclusion, based on recent work, that, "The immature kernel almost certainly abstracts food from the culm after harvest." Their data appear to indicate that the kernel is able to extract a limited amount of food material from the culm even when it is severed and dried immediately. They say, "Conceding this to be a fact, it is probable that the changes that occur in shocks of grain harvested at maturity may be of importance."

While there is considerable variance in the results of the work reviewed, the indications are that when grain is harvested earlier than the stage when the majority of the kernels are in the hard dough a reduction in both yield and weight per bushel is likely to result. Weather conditions following the cutting may have considerable effect on the outcome.

Considering the effect of cutting before maturity on the grain only, better quality has not been shown to result from the practice.

When both the grain and straw are to be fed on the farm, the data indicate that cutting when the spikes or panicles have turned yellow but the leaves and stems are still green is good practice in order to minimize the leaching of valuable materials (18) from the vegetative parts.

Grain heavily attacked by black stem rust is cut off more or less completely from its moisture and food supplies. Although there appears to be no sound basis to justify the practice, such grain has been harvested considerably on the green side with the expectation of securing increased yields of better quality grain.

Ellis (7) harvested wheat badly infested with black stem rust at three-day intervals beginning at the late milk stage. The grain was cured in shocks in the ordinary manner. Cutting in the late-milk stage resulted in grain weighing 56 pounds per bushel, while that cut at the stage where the grain was firm as determined by not being able to crush it between the thumb and finger weighed 59 pounds per bushel. The highest yields were also secured from the wheat cut in the "firm" stage. The conclusion is that rusted wheat should not be cut earlier than grain not attacked by rust.

The results from two cuttings of wheat affected with black stem rust to the extent of 75 to 80% are given by Stoa (26). The first cutting was made when the spikes were beginning to change color and the kernels were in the dough stage. The second cutting was made five days later when the crop was mature. The sheaves were shocked out doors. The grain from the cutting made when mature had the advantage in yield per acre, test weight per bushel, weight per bushel, weight per 1,000 kernels, and protein percentage, but the differences were not significant. In loaf volume and color the flour from the grain harvested at maturity was somewhat superior.

METHOD OF WORK

The results reported in this article were secured during the summer of 1925. On March 28, 20 plats 132 x 8 feet were sown to Marquis wheat at the rate of 90 pounds per acre and on April 6 the same number of plats of like size were sown to Victory oats at the rate of 64 pounds per acre. Duplicate plats of each grain were harvested when, according to previous experience, they were approximately in the stage of development that would require nine days for them to mature and daily following that time to maturity. The estimates of the number of days required to mature when the daily cutting was started was close enough in 1925 so that the last plat of each crop was cut at about the stage it would be considerably mature. No rain or other unfavorable weather conditions which would interrupt the carrying out of the regular daily routine occurred during the period covered by the work. The daily routine was as follows:

1. *Taking samples from the standing grain.*—Several small areas were harvested early each morning in different parts of the plats to be harvested that day so as to obtain a representative sample of about the size of two ordinary grain bundles. These samples were put in canvas bags to minimize loss of moisture and brought to the laboratory.

2. *Preparation of the samples.*—In caring for the samples after they were cut, the work was done rapidly so as to minimize the losses of moisture and the same technic was followed each day. Each sample was divided into two approximately equal parts which were again divided as follows: The first part was divided into samples with (a) the grain attached to the rachis, (b) the spikelets stripped from the rachis, (c) the rachis only, (d) the first 8 inches of straw below rachis, and (e) the second 8 inches of straw. These prepared samples were placed in cotton bags, put immediately into a steam-heated oven, and left for five days. From each of the samples described above enough material was taken to make a representative lot

and two weighing bottles were filled from each lot. The material was cut up fine where this was necessary. These bottles were weighed and then transferred immediately to an electric drying oven where they were dried for three days at 100°C. Dry matter percentages were calculated from these samples. The second part was divided into samples with (a) the grain attached to the rachis, (b) the spikelets stripped from the rachis, (c) the grain with 8 inches of straw, (d) the grain with 16 inches of straw, and (e) the grain with all the straw. These samples were put in cotton flour bags and hung under the cornice of a roof to dry slowly.

3. *Harvesting the plats.*—At 8 a. m., areas of 6 square yards were removed from each of the plats harvested that day for yield determinations and the rest of the grain was cut immediately with the binder. The 6-square-yard sample was shocked on the inside of the bundles from the same plat. Loose fitting canvas covers were put over the shocks to protect them from rain.

4. *Taking the samples from the shocks.*—For observing the effect of curing in the shock, samples were taken from several parts of the shocks at 3-day intervals, beginning 12 days after the first cutting had been made. It was necessary to defer this part of the work until the samples from the standing grain had been cared for.

5. *Preparing the dried samples for the final determinations.*—After the material had dried in the oven or cured in the bags under the cornice or in the shocks the desired length of time, they were threshed and bagged.

6. *Making the determinations.*—(a) Weight per 1,000 kernels was determined by counting duplicate lots of 250 kernels and weighing them on an enclosed torsion balance. The weight per 1,000 was computed from two determinations that checked well. (b) The bushel weight was obtained according to the method specified in the Handbook of Official Grain Standards for wheat, shelled corn, oats, and rye. (c) The percentage of green kernels was determined by counting the number in the samples used for 1,000 kernel weights that in wheat were either distinctly green or had a tinge of green along the crease and in oats all kernels that were distinctly green at the tips or faintly green on the hulls and computing to a percentage basis. (d) Percentage of hulls. In oats the hulls were removed from the weighed 250-kernel samples, the kernels weighed again, and the percentages of hulls computed. (e) All chemical determinations were made under the supervision of the Division of Biochemistry. Nitrogen determinations were made by the Kjeldahl

method and the ash content determined by heating the crucibles containing the samples in an electric muffle.

COMPUTING PROBABLE ERROR

The probable error for dry matter determinations, 1,000-kernel weight, percentage of hulls, and yield were computed by the pairing method from the results of the duplicate determinations. Differences divided by their probable errors amounting to 3.2 or better are considered significant.

DESCRIPTION OF PLANTS AT EACH DATE OF HARVEST

The phrases "9 days early," etc., are indefinite. In order to make them more definite, as full descriptions were made of the crop harvested each day as time would permit. Therefore, at each cutting the crop was examined very closely and the stage of maturity was noted as indicated by the appearance of the parts of the plants. The terminal spikelets in both wheat and oats are the first to show signs of maturing. Unless otherwise stated, the condition of the endosperm of the terminal spikelet is meant.

I. WHEAT—FIRST CUTTING JULY 15 AND ON SUCCESSIVE DAYS THEREAFTER

1. *Nine days early.*—Terminal spikelets green, kernels in thick milk stage, first and second 8 inches of straw green, leaves green.
2. *Eight days early.*—Terminal spikelets turned slightly yellow, kernels in thick creamy stage, first 8 inches of straw green, leaves green.
3. *Seven days early.*—Terminal spikelets turning yellow, kernels in hard dough, first and second 8 inches of straw green, leaves green.
4. *Six days early.*—Terminal spikelets slightly yellow, glumes brown at sides, kernels in thick dough, first 8 inches of straw slightly turning yellow, second 8 inches green, leaves green.
5. *Four days early.*—Spikelets turning yellow with green tinge except at the tips, kernels in hard dough, majority of necks yellow except a few with light green tinge; first and second 8 inches of straw light green; leaf blades brown; leaf sheaths green.
6. *Three days early.*—Terminal spikelets yellow and other six below it yellow with glumes still light green, kernels in upper spikelets very hard dough, kernels in lower spikelets medium hard dough, neck yellow tinged green, straw below neck to first leaf sheath yellow tinged green, leaf blades yellow to brown.
7. *Two days early.*—Spikelets practically all yellow except one or two at the base tinged green; rachis yellow; kernels in upper spikelets

in wet starchy stage, in lower spikelets in hard dough; neck yellow, straw from neck to first sheath yellow slightly tinged green; leaf blades yellow to brown; leaf sheaths yellow with green tinge.

8. *One day early, cut on July 23.*—Spikelets yellow with a few faintly green ones at the lower end of the spikes; rachis yellow but not brittle; kernels in upper spikelets in starchy stage; kernels in lower spikelets in very hard dough; neck yellow; straw from neck to first leaf sheath yellow to light green; straw from node of first sheath to second sheath greenish yellow; leaf blades brown, not brittle; leaf sheaths yellow with green tinge, not brittle: internodes of straw light green.

9. *Mature.*—The glumes of the spikelets from yellow to brown; rachis pale yellow, not brittle; kernels from starchy to hard vitreous, neck brown; straw from neck to first sheath brown; straw from node of first sheaths to second sheath yellow; leaf blades brown, not brittle; leaf sheaths yellow with a faint green shade; internodes of straw from light green to yellow.

II. OATS—FIRST CUTTING ON JULY 15 AND ON SUCCESSIVE DAYS THEREAFTER

1. *Nine days early.*—Terminal spikelets green, kernels in thin milk stage; first and second 8 inches of straw green, leaves green.

2. *Eight days early.*—Terminal spikelets green, kernels in thin milk stage, first and second 8 inches of straw green, leaves green.

3. *Seven days early.* —Terminal spikelets turning yellow, kernels in thick milk stage, first and second 8 inches of straw green, leaves green.

4. *Six days early.*—Terminal four or five spikelets yellow, kernels in thin dough, first and second 8 inches of straw green, leaves green.

5. *Four days early.*—Terminal spikelets yellow; first two internodes of rachis yellow, next two internodes yellow with green tinge, the lowest ones green; kernels at the terminal in hard dough, others in thick milk; leaf sheaths green; leaf blades brown.

6. *Three days early.*—Spikelets yellow, rachis yellow except the lowest two internodes yellow with green tinge; kernels in upper spikelets very hard dough, kernels in lower spikelets soft dough; neck yellow tinged with light green, the lowest rachis node distinctly green; straw from neck to first leaf sheaths yellow tinged green; leaves brown; leaf sheaths yellow with green tinge.

7. *Two days early.*—Spikelets yellow, except one at the lowest node yellow with green tinge; upper internodes of the rachis yellow and the lowest two still greenish yellow; rachis greenish yellow;

kernels in upper spikelets in wet starchy stage, kernels in lower spikelets in hard dough; neck yellow with green tinge; straw from neck to first sheath light greenish yellow, from the second internode to second sheath greenish yellow; leaf sheath from brown to green; leaf blades not brittle.

8. *One day early.*—Spikelets all yellow; rachis yellow, not brittle with nodes faintly green; kernels of upper spikelets in wet starchy stage; neck yellow; straw from neck to first sheath yellow to brown, from node of first sheath to second sheath greenish yellow; leaf blades brown, not brittle; leaf sheath slightly greenish yellow; internodes of straw light green to yellow.

9. *Mature.*—Entire panicles yellow: rachis yellow; kernels starchy; neck yellow; straw from neck to second sheath yellow; leaf blades brown, not brittle; leaf sheath yellow; internodes of straw light yellow.

EXPERIMENTAL RESULTS

The results secured with wheat are given and discussed first followed by a similar treatment of the data for oats. Since yield of grain is of the greatest interest, it is considered first.

RESULTS WITH WHEAT

YIELD OF GRAIN PER ACRE

As yield of grain is one of the most variable determinations in crops grown under field conditions, it is not usual to draw conclusions from the results from only one year. However, a comparison of the results for one year is at least indicative. Examining the yields of wheat as recorded in Table 1, it is seen that there is a difference in yield of more than 6 bushels per acre between wheat cut when the terminal spikelets were still green and the kernels in the thick milk stage (nine days early) and that cut at maturity. But when the probable error of the experiment for the single season is taken into consideration, this difference is not statistically significant. The difference divided by the probable error is 2.7, and since this is less than 3.2, it is not considered significant. However, the yields increase fairly consistently as the grain becomes more mature before cutting.

WEIGHT PER BUSHEL

Since the yield from the wheat cut in the most immature stage was lower than that from the wheat cut at maturity, although the difference was not considered significant, differences in weight per bushel might be expected. The data recorded in Table 1 substantiate this. From the standpoint of market value, as indicated by weight

TABLE I.—*Comparison of the effects of harvesting wheat at various stages of maturity on the yield of grain, straw, and weight per 1,000 kernels.*

Days to maturity when cut	Yield of grain per acre, bushels	Weight per bushel, pounds	Yield of straw per acre, tons	Weight per 1,000 kernels in grams							
				Dried in oven		Dried in air		With straw attached			Dried in shock
				Not attached to rachis	Attached to rachis	Not attached to rachis	Attached to rachis	8 inches	16 inches	All	
9	28.37	55.8	2.18	25.32	25.40	25.40	25.64	24.28	24.68	24.68	25.64
8	27.61	57.0	2.34	29.36	26.56	——	25.16	28.96	28.52	26.96	27.72
7	28.72	58.1	1.93	29.44	30.16	28.08	28.52	27.64	28.88	27.80	29.64
6	30.05	58.8	1.74	31.20	31.56	32.08	31.40	30.60	31.48	31.64	30.76
4	31.44	59.7	1.72	33.32	32.12	32.12	31.44	31.96	32.56	31.52	31.56
3	33.11	59.9	2.02	32.44	32.72	31.92	31.48	31.72	32.00	32.68	33.60
2	32.38	60.3	1.82	33.76	34.24	31.72	32.36	33.32	32.32	32.40	32.96
1	32.17	60.2	1.75	33.76	33.40	33.44	33.52	33.00	33.40	33.00	33.80
Mature	34.89	60.6	1.90	34.36	34.48	33.44	33.44	33.76	33.24	33.12	34.32

per bushel, wheat cut when the terminal spikelets had turned yellow and the kernels were in the hard dough stage (seven days early) up to maturity and cured in the shock graded No. 1, while wheat cut a day earlier graded No. 2 and that cut two days earlier No. 3. Wheat cut at maturity weighed 60.6 pounds per bushel, while that cut three days earlier weighed 59.9 pounds per bushel. The difference in weight per bushel, 0.7 pound, divided by the probable error gives 4.0+. Thus, while the difference in weight of 0.7 pound per bushel does not change the market grade, still it is significant as measured by its probable error. Kiesselbach (16) and Bedford (3) secured data on the same order.

WEIGHT PER 1,000 KERNELS

With indications of increased yield per acre and weight per bushel as the grain approached maturity, increases in weights of the kernels should be shown. Weights in grams per 1,000 kernels for the grain harvested at successive stages of development and cured at different rates are recorded in Table 1. The weights of the kernels cured in the shock, as given in the last column, are the only ones discussed here. The weights secured from the other treatment will be discussed under a later topic. It is to be noted that the increase is rapid from the time the kernels in the terminal spikelets were in the thick milk (nine days early) to the time the lower kernels were in the dough stage (four days early). After that the increase is fairly uniform and gradual. By comparing the grain cut when the kernels in the lower spikelets were in the medium hard dough stage (three days early) with that cut at maturity, the difference is three times its probable error in favor of the matured crop. After this stage (three days early) the differences are immaterial as interpreted by the experimental errors involved. These results confirm the data obtained by previous workers, including McDowell (20), Saunders (22), Shutt (24), Olson (21), Kiesselbach (16), Thatcher (29), and others.

YIELD OF STRAW PER ACRE

It is a known fact that plants take up and elaborate nutrients rapidly in the stages of vegetative growth up to full bloom and that under favorable conditions much of this is later translocated to the more permanent storage organs. Accordingly, from this it appears that early cuttings should give higher yields of straw. This appeared to be the case when the yields of straw recorded in Table 1 are considered. The yield of straw for the wheat cut at the earliest stage was 2.18 ± 0.0872 tons and that of wheat cut at maturity 1.90 ± 0.0760 tons per acre, a difference of 0.28 ton in favor of the nine days

TABLE 2.—*Percentage of green kernels in wheat and oats and of hulls in oats harvested seven days early and at maturity when dried in various ways.*

Stage of maturity when cut	Dried in oven		Dried slowly in air					Dried in shock, all straw attached
	Not attached to rachis	Attached to rachis	Not attached to rachis	Attached to rachis	With straw attached			
					8 inches	16 inches	All	
Wheat, Percentage of Green Kernels Based on Number								
7 days early	21.00	30.40	0	0	0	0	0	0
Mature	6.00	0.00	0	0	0	0	0	0
Differences	15.60	30.40	0	0	0	0	0	0
Oats, Percentage of Green Kernels Based on Number								
7 days early	84.00	71.40	35.80	30.60	14.00	14.40	18.60	16.60
Mature	0.00	4.60	4.60	5.20	4.40	4.20	1.80	3.60
Differences	84.00	66.80	31.20	25.40	9.60	10.20	16.80	13.00
Oats, Percentage of Hulls Based on Weight								
7 days early	34.04	33.58	36.41	35.05	35.50	40.89	38.28	34.83
Mature	28.50	29.57	31.12	——	30.15	30.53	29.83	28.53
Differences	5.54	4.01	5.29	——	5.35	10.36	8.45	6.30

early cutting. When the interpretation is made in the light of the probable error, however, this is not a significant difference. Here again, seasonal fluctuations are encountered which call for further trials.

PERCENTAGE OF GREEN KERNELS

Since the color of the kernel has a great deal to do with the quality of the grain, it is of interest also to note the percentage of green kernels in the early cuttings as compared with the normally harvested matured grains. Examination of the results recorded in Table 2 show that, when the wheat was cured slowly, either hanging in the air or shocked, there were no green kernels even where the cutting was made nine days before maturity. However, when the immature grain was dried rapidly in the oven, a considerable percentage of the kernels remained green in color.

PERCENTAGE OF DRY MATTER

Samples for dry matter determinations were not taken from the grain harvested nine and eight days early soon enough after the material had been brought in to give accurate results. Therefore, they are omitted for both wheat and oats. It is to be noted here that the dry matter content of the different parts of wheat given in Table 3 increased rather regularly as the plant approached maturity, although weather conditions caused some fluctuations. Since the dry matter content has a great deal to do with the translocation of food material, it will be discussed again in connection with that topic.

RESULTS WITH OATS

YIELD OF GRAIN PER ACRE

Victory oats was studied in the same way as Marquis wheat. The yields per acre shown in Table 4 fluctuate considerably more than the yields of wheat. Here again, although the indications are that the yields from the early cuttings are less than from the cuttings made at maturity, it is necessary to secure data over a period of years before drawing conclusions. There is no explanation available for the higher yields secured for cuttings made seven days and four days early.

WEIGHT PER BUSHEL

Interpreting weights per bushel for the various cuttings in the light of the probable error, the significant difference is found to begin with the grain cut at seven days early as compared with the matured crops. The grain cut nine, eight, and seven days early graded No. 2 on account of weight per bushel, while the rest graded No. 1 on this factor.

TABLE 3.—*Percentage of dry matter of different parts of wheat and oat plants at time of cutting at different stages of development.*

Stage of maturity	Grain and chaff	Grain, chaff, and rachis	Rachis only	Straw, 1st 8 inches	Straw, 2nd 8 inches
		Wheat			
7 days early	50.23	51.10	48.10	45.02	44.18
6 days early	52.83	50.22	49.24	45.92	40.05
4 days early	55.85	55.80	53.08	46.06	47.79
3 days early	53.84	54.06	52.02	44.32	49.80
2 days early	59.07	55.84	54.75	45.47	47.58
1 day early	62.85	63.57	65.38	51.45	55.91
Mature	62.36	61.75	58.35	48.70	49.21
		Oats			
7 days early	49.08	44.30	41.09	27.46	23.86
6 days early	49.41	49.52	39.20	30.07	25.93
4 days early	53.03	54.60	38.53	33.17	27.62
3 days early	55.03	55.42	36.25	34.81	30.71
2 days early	54.45	55.92	37.34	34.69	31.90
1 day early	66.95	72.49	43.66	43.31	37.76
Mature	62.81	68.60	41.55	40.73	34.35

TABLE 4.—*Effect of harvesting oats at various stages of maturity on yield of grain and straw, weight per bushel, and weight per 1,000 kernels.*

Stage of maturity when cut	Yield of grain per acre, bushels	Weight per bushel, pounds	Yield of straw per acre, tons	Weight per 1,000 kernels in grams							
				Dried in oven		Dried in air					Dried in shock
				Not attached to rachis	Attached to rachis	Not attached to rachis	Attached to rachis	With straw attached			
								8 inches	16 inches	All	
9 days early	79.27	28.6	1.60	19.16	19.52	——	19.00	18.80	19.16	19.52	19.68
8 days early	74.32	29.7	1.45	19.56	19.05	21.12	——	19.88	18.92	20.72	21.44
7 days early	81.67	31.1	1.56	21.16	22.64	22.96	22.88	22.08	21.48	21.52	23.00
6 days early	75.25	32.9	1.21	22.48	23.76	24.80	23.96	23.84	24.20	24.80	21.28
4 days early	93.77	34.7	1.21	24.92	24.56	24.92	26.12	25.32	25.88	24.88	25.12
3 days early	74.28	33.9	1.53	24.88	25.08	26.08	27.08	27.16	26.52	26.28	26.12
2 days early	75.58	35.4	1.50	26.44	26.60	26.52	26.44	26.64	26.80	28.36	25.76
1 day early	76.00	35.1	1.20	26.28	26.28	27.04	25.88	27.80	26.96	27.32	26.28
Mature	86.47	34.6	1.33	26.32	26.04	26.72	——	26.80	27.12	28.40	26.36

WEIGHT PER 1,000 KERNELS

The weight per 1,000 kernels for shock-cured grain, as shown in Table 4, increased rapidly from nine days early to four days early. After this the increase was slight.

YIELD OF STRAW PER ACRE

So far as straw is concerned, an increase in yield of 0.2 to 0.3 ton was obtained in the cuttings made nine, eight, and seven days early as compared with cuttings from the matured crop. However, the fluctuations are large and more data must be secured before conclusions can be drawn.

PERCENTAGE OF GREEN KERNELS AND HULLS

As in the case of wheat the percentage of green kernels is given on the basis of numbers. The record tabulated in Table 2 shows that there was a large number of green kernels in the crop harvested seven days early and dried in the oven. However, the percentage was very much lower when cured in the shock than when cured in the oven. In the same table it is to be noted also that the percentage of hulls of oats cut seven days early is consistently higher than for oats cut at maturity. In the case of shocked grain this difference is about 6%.

PERCENTAGE OF DRY MATTER

The percentages of dry matter are shown in Table 3. These indicate that there was an increase as the crop approached maturity in approximately the same way as in the case of wheat. The increase is very rapid from two days early to maturity, as the figures for the grain and chaff indicate 54.45 to 62.81%, first 8 inches of straw from 34.69 to 40.73%, and second 8 inches of straw from 31.90 to 34.35%. The percentages of dry matter in the rachis did not increase regularly. Some of this variation is undoubtedly due to failure to secure representative samples. This appears to agree with the results of Keitt and Tarbox (15) who observed that the increase in the total dry matter was very rapid during the last few days of the maturity of the plant. Previous to that time the increase was regular but not rapid. For oats, as for wheat, the dry matter percentage is higher at one day early than at maturity. There is no explanation available for this. Oats was somewhat more immature at seven days early than wheat. This difference is particularly noticeable in the straw where the dry matter percentages are regularly considerably lower than for wheat. This difference would appear to favor translocation in oats following premature cutting as compared with wheat.

TRANSLOCATION OF FOOD MATERIAL

Previous researches have shown that plants take up mineral nutrients very rapidly in the early stages and the amounts taken up with the exception of nitrogen attain their maximum at the time of full bloom or shortly after. These nutrients are elaborated and portions used up for growth metabolism and portions stored temporarily in the vegetative organs from which they are translocated later to more permanent storage organs, commonly the seeds or the underground parts.

During this process of translocation, the amount of moisture present plays an important rôle. Olson (21), in his studies on the changes that occur during the development of wheat, observed that translocation from the vegetative parts to the kernels ceased when the moisture content fell below 40%. Later, Harlan (11) arrived at the conclusion that cessation of translocation occurred at the point at which the moisture content dropped to 42%. In still later work, Harlan (13) comes to the conclusion that, since the 42.8% mentioned in his previous article represents an average for all kernels, a percentage somewhat lower than that is more nearly correct.

The moisture content of the different parts of the plants were determined at the time of cutting to ascertain at what stage of maturity further translocation would be inhibited. In Table 3 are recorded the results which show that there was enough water present, according to the findings of previous investigations, in all of the plant parts on which determinations were made, except at the one day early and mature stages, to permit translocation to take place.

If material was translocated to any extent from the straw to the grain in the cuttings made before maturity, this should be evident in an increase in weight per 1,000 kernels of the grain dried slowly in the air with various amounts of vegetative parts attached and in the shock with all straw attached as compared with the weight when dried rapidly in the oven.

There is a fairly regular increase in weight per 1,000 kernels as shown in Tables 1 and 4 for the material dried rapidly in the oven from 25.32 to 34.36 grams for wheat and 19.16 to 26.32 grams for oats from the earliest harvest date to maturity, respectively. In the standing grain, therefore, according to the usual course of events in the development of plants as ascertained by other workers, there was a large translocation of materials from the vegetative parts to the grain from nine days early to maturity.

For both the wheat and oats the weights per 1,000 kernels for any date of sampling are as high for the grain dried rapidly in the oven

TABLE 5.—*Effect of curing wheat and oats in shocks after cutting at various stages of maturity on the weight per 1,000 kernels and percentage of dry matter.*

	Days after cutting											
	12		15		18		21		24		27	
Stage of maturity	Weight per 1,000 kernels, grams	Per cent dry matter	Weight per 1,000 kernels, grams	Per cent dry matter	Weight per 1,000 kernels, grams	Per cent dry matter	Weight per 1,000 kernels, grams	Per cent dry matter	Weight per 1,000 kernels, grams	Per cent dry matter	Weight per 1,000 kernels, grams	Per cent dry matter
						Wheat						
9 days early	26.12	77.50	26.84	85.98	24.44	81.87	26.84	88.34	28.72	85.33	28.36	89.38
8 days early	28.80	84.20	29.92	84.02	28.00	86.04	29.04	87.32	29.16	87.41	27.04	86.55
7 days early	28.40	84.21	28.76	83.64	29.08	87.54	28.28	85.02	28.80	87.65	29.48	86.50
6 days early	31.52	85.25	28.44	87.66	31.56	87.28	31.80	85.66	32.92	87.58	30.36	84.80
4 days early	31.52	83.26	32.68	87.26	31.52	86.53	31.32	87.22	33.40	85.89	33.12	86.31
3 days early	33.52	83.85	35.12	87.33	33.60	83.89	35.12	89.00	34.88	82.62	33.68	87.40
2 days early	34.48	85.68	34.20	87.71	33.16	88.15	34.12	87.18	34.48	87.69	34.56	88.78
1 day early	32.04	86.94	34.52	81.05	33.08	88.37	33.40	85.07	34.48	86.12	32.96	87.36
Mature	34.28	87.26	33.72	84.90	33.40	88.58	34.00	84.98	34.24	86.04	34.44	87.57
						Oats						
9 days early	20.16	81.05	19.60	86.70	19.56	84.22	19.24	87.89	20.20	86.46	19.96	90.18
8 days early	17.12	86.49	19.56	82.60	19.60	87.11	19.76	87.96	20.24	88.25	19.28	85.87
7 days early	20.52	85.21	24.96	84.32	22.20	88.05	21.88	85.35	20.08	87.84	23.28	87.06
6 days early	24.56	85.42	22.72	84.96	22.20	88.08	23.44	88.81	23.96	88.65	23.28	83.37
4 days early	27.08	84.56	25.00	89.38	25.40	84.67	24.92	88.12	22.88	86.42	23.56	87.77
3 days early	25.64	83.87	25.20	88.10	25.84	83.67	27.68	88.25	25.84	84.14	25.12	87.08
2 days early	26.92	86.28	26.80	87.51	26.80	87.47	26.56	87.58	——	88.36	27.36	88.96
1 day early	25.72	89.07	26.52	83.64	27.84	88.29	27.36	87.00	26.84	87.80	26.92	89.11
Mature	27.92	87.16	27.72	86.63	26.92	89.19	25.92	84.35	26.36	88.12	26.52	88.22

TABLE 6.—*Percentages of nitrogen, protein (N x 5.7 for wheat and 6.25 for oats), and ash in the straw and chaff of wheat and oats harvested seven days early and at maturity and cured in various ways.*

Stage of maturity when cut	Dried in the oven				Dried slowly in the air				Dried in shock			
	Glumes	Rachis	1st 8 inches straw	2nd 8 inches straw	Glumes	Rachis	1st 8 inches straw	2nd 8 inches straw	Glumes	Rachis	1st 8 inches straw	2nd 8 inches straw
					Wheat							
Nitrogen												
7 days early			1.13	0.99	0.70		0.87	0.94	0.71		0.96	1.02
Mature			0.45	0.44	0.44		0.40	0.54	0.49		0.49	0.48
Differences			0.68	0.55	0.26		0.47	0.40	0.22		0.47	0.54
Protein												
7 days early			6.43	5.66	4.01		4.95	5.35	4.07		5.47	5.81
Mature			2.58	2.57	2.50		2.28	3.10	2.82		2.82	2.76
Differences			3.85	3.09	1.51		2.67	2.25	1.25		2.65	3.05
Ash												
7 days early			5.34	9.82	14.19		6.15	10.77	15.15		5.99	7.85
Mature			7.65	8.82	14.79		7.29	9.49	14.45		8.02	7.93
Differences			—2.31	1.00	—0.60		—1.14	1.28	0.70		—2.03	—0.08
					Oats							
Nitrogen												
7 days early	1.66	——	0.83	0.65	1.41	0.62	0.86	0.43	1.54	0.55	0.55	0.42
Mature	1.50	——	0.38	0.35	1.07	0.53	0.39	0.30	0.94	0.45	0.42	0.32
Differences	0.16	——	0.45	0.30	0.34	0.09	0.47	0.13	0.60	0.10	0.13	0.10
Protein												
7 days early	10.40	——	5.18	4.06	8.81	3.85	5.37	2.70	9.65	3.46	3.46	2.62
Mature	9.40	——	2.37	2.21	6.68	3.31	2.46	1.90	5.87	2.84	2.65	2.03
Differences	1.00	——	2.81	1.85	2.13	0.54	2.91	0.80	3.78	0.62	0.81	0.59
Ash												
7 days early	9.05	——	13.42	11.85	11.41	6.20	11.59	9.97	12.92	8.78	12.71	9.63
Mature	9.51	——	12.13	11.19	12.93	7.50	13.80	9.13	14.41	8.50	11.51	10.00
Differences	—0.46	——	1.29	0.67	—1.52	—1.30	—2.21	0.84	—1.49	0.28	1.20	—0.37

with only the chaff or the chaff and rachis attached as when curing proceeded more slowly with the same or more of the vegetative portions attached. This indicates that translocation of materials from the leaves and stems to the kernels did not occur in amounts large enough to be detected by the method of work followed.

The weights per bushel and yields per acre indicate the same results.

Furthermore, if a movement of material from the vegatative parts to the grain occurred, the percentage of hulls in the oats cured in the shock ought to be lower than for the samples dried rapidly in the oven. However, the percentages given in Table 2 are not significantly different. They are 34.83% for the grain cured in the shock and 34.04% for the grain dried rapidly in the oven. It appears, therefore, that little or no translocation of food material took place in wheat or oats after premature cutting in this experiment regardless of the amount of vegetative parts attached to the grain under rapid or slow curing conditions.

MOISTURE CONTENT OF GRAIN IN THE SHOCK

Since there appear to be no data available showing the rate of curing and changes that take place after the grain is cut and placed in the shock, it was planned to take samples at three-day intervals from the shocked grain cut at different stages of maturity

Owing to the large amount of work necessary to secure the other data each day, sampling from the shock could not be started until 12 days after the first cutting was made. There is a fair agreement in both the weights per 1,000 kernels and the percentages of dry matter in the grain harvested at the successive stages on the six days they were sampled from the shock. The samples of wheat harvested one day early and at maturity and of oats harvested at maturity taken on the twenty-first day are low in dry matter as compared with the same determinations on the preceding and following days. At that time and during the five days following, as shown in Table 5, the moisture content in all parts of the harvested plants was too low to permit further appreciable translocation in either wheat or oats. Work is now under way to ascertain the changes that take place in grain harvested at different stages of maturity and cured in the shock.

NITROGEN AND ASH DETERMINATIONS

This leads up naturally to a consideration of any internal changes that may have occurred in wheat and oats grown under the same conditions and cut at various stages of maturity. It is an established fact that early in their development plants rapidly take up mineral nutrients from the soil, elaborate these materials, and store them in the stems and leaves and later transfer them to the grains. Accordingly, a larger amount of stored material should be found in the different portions of the straw when cutting takes place before the grain is well formed. A limited number of determinations were made on straw and grain and the results for the straw are given in Table 6.

Dried under the same conditions, the glumes, rachis, first 8 inches of straw, and second 8 inches of straw for both wheat and oats were higher in nitrogen content when harvested seven days before maturity than at maturity. The differences in nitrogen percentage under conditions which brought about rapid and gradual drying are brought out in Table 7.

TABLE 7.– *Percentages of nitrogen in straw from grain harvested seven days early and dried rapidly as compared with slow drying.*

Method of curing	1st 8 inches	2nd 8 inches
Wheat		
Rapidly in oven	1.13	0.99
Slowly in shock	0.96	1.02
Differences	0.17	– 0.03
Rapidly in oven	1.13	0.99
Slowly, hung in dry location	0.87	0.94
Differences	0.26	0.05
Oats		
Rapidly in oven	0.83	0.65
Slowly in shock	0.55	0.42
Differences	0.28	0.23
Rapidly in oven	0.83	0.65
Slowly in shock	0.86	0.43
Differences	– 0.03	0.22

Knowing to some extent what has happened in the straw, the composition of the grain may be considered next. The results of this study are given in Table 8. In accordance with the growing interest in marketing wheat on the basis of protein percentage, it is natural to consider first what change has taken place, if any, in this important constituent. Comparisons are made between wheat harvested seven days early and that harvested at maturity and cured in three different ways. In each instance the percentage of nitrogen in the grain harvested at maturity is somewhat lower than in the grain harvested seven days early. These results for wheat are not in line with the results obtained by Brenchley and Hall (4), Thatcher (29), Woodman and Engledow (31), and Kiesselbach (16) with wheat and Harlan (11) with barley where a slight increase in percentage of total nitrogen as the grain approached maturity was shown.

TABLE 8.—*Percentages of nitrogen, protein ($N \times 5.7$), and ash in the grain of wheat and oats harvested seven days early and at maturity and cured in various ways.*

Stage of maturity when cut	Dried rapidly in oven		Dried slowly in air					Dried in shock, all straw attached
	Not attached to rachis	Attached to rachis	Not attached to rachis	Attached to rachis	With straw attached			
					8 inches	16 inches	All	
			Wheat					
Nitrogen								
7 days early	2.47	2.47	2.46	2.41	2.47	2.48	2.37	2.32
Mature	2.28	2.19	2.30	2.26	2.33	2.24	2.28	2.28
Differences	0.19	0.28	0.16	0.15	0.14	0.24	0.09	0.04
Protein								
7 days early	14.10	14.10	14.01	13.75	14.10	14.13	13.52	13.22
Mature	12.94	12.48	13.11	12.90	13.30	12.79	12.99	12.99
Differences	1.16	1.62	0.90	0.85	0.80	1.34	0.53	0.23
Ash								
7 days early	2.26	2.10	2.18	2.28	2.35	2.30	2.24	1.96
Mature	2.06	1.87	1.90	1.93	2.18	2.08	1.98	2.01
Differences	0.20	0.23	0.28	0.35	0.17	0.22	0.26	—0.05
			Oats					
Nitrogen								
7 days early	1.67	1.83	1.76	1.92	2.08	1.81	1.99	2.11
Mature	1.99	1.90	1.97	——	1.91	2.04	2.00	1.93
Differences	—0.32	—0.07	—0.21	——	0.17	—0.23	—0.01	0.18
Protein								
7 days early	10.44	11.46	11.00	12.01	12.99	11.34	12.46	13.18
Mature	12.46	11.90	12.31	——	11.96	12.79	12.54	12.07
Differences	—2.02	—0.44	—1.31	——	1.03	—1.45	—0.08	1.11
Ash								
7 days early	4.25	4.09	4.27	4.17	4.64	5.39	4.17	4.26
Mature	4.34	4.66	4.45	——	4.41	3.90	5.00	4.77
Differences	—0.09	—0.37	—0.18	——	0.23	1.49	—0.83	—0.51

TABLE 9.—*Percentages of nitrogen, protein (N x 5.7), and ash in hulled oats harvested seven days early and at maturity and cured in various ways.*

Stage of maturity when cut	Dried rapidly in oven		Dried slowly in the air					Dried in shock, all straw attached
	Not attached to rachis	Attached to rachis	Not attached to rachis	Attached to rachis	With straw attached			
					8 inches	16 inches	All	
			Nitrogen					
7 days early	2.31	2.27	2.27	2.42	2.47	2.73	2.84	2.95
Mature	2.57	2.59	2.57	——	2.64	2.64	2.54	2.53
Differences	—0.26	—0.32	—0.30	——	—0.17	0.09	0.30	0.42
			Protein					
7 days early	14.43	14.21	14.21	15.12	15.43	17.09	17.77	18.44
Mature	16.09	16.21	16.06	——	16.52	16.52	15.87	15.81
Differences	—1.66	—2.00	—1.85	——	—1.09	0.57	1.90	2.63
			Ash					
7 days early	2.51	2.85	2.71	3.00	2.43	2.76	2.92	2.77
Mature	2.95	3.09	2.53	——	2.96	2.82	2.38	2.74
Differences	—0.44	—0.24	0.18	——	— 0.53	—0.06	0.54	0.03

The results secured by the workers mentioned above were from samples of uniform maturity, while the present determinations were made on samples of bulk grain as it stood in the field, thus representing farm conditions. Further determinations of nitrogen percentages for wheat harvested in this way are necessary before drawing conclusions.

The results secured for oats differ from those obtained from wheat as far as nitrogen and ash are concerned. This fact is brought out by the differences shown in Table 8 between the nitrogen and ash percentages for oats cut seven days early and at maturity. There is an increase in nitrogen in favor of the matured oats with the hulls on, both when dried in the oven and in the air. However, the shocked grain cut seven days early appears to have a slight advantage over that cut at maturity. The early harvested oats has the higher percentage of hulls. Therefore, the hulls were removed and the kernels only analyzed. The results (Table 9) show about the same differences as with the hulls on. The ash percentages were higher in the grain cut at maturity in five out of seven cases.

As previously noted, there are indications of translocation of food materials from the straw, so the comparisons given in Table 10 were made to see whether there were any corresponding changes in the grain of wheat and oats.

TABLE 10.—*Nitrogen percentages in the grain of wheat and oats harvested seven days early and dried out rapidly as compared with slow curing in the shock.*

Method of curing	7 days early	Mature
Wheat		
Slowly in shock	2.32	2.28
Rapidly in oven	2.47	2.28
Difference	—0.15	0.00
Slowly in bags	2.37	2.28
Rapidly in oven	2.47	2.28
Difference	—0.10	0.00
Oats		
Slowly in shock	2.11	1.93
Rapidly in oven	1.67	1.99
Difference	0.44	—0.06
Slowly in bags	1.99	2.00
Rapidly in oven	1.67	1.99
Difference	0.32	0.01

For the wheat harvested seven days early the nitrogen percentages are slightly higher for grain dried rapidly in the oven as compared with slow drying. The grain harvested at maturity had the same composition regardless of the method of curing.

The oats cut seven days before maturity were higher in nitrogen when cured slowly than when dried rapidly in the oven. Harvested at maturity the percentages of nitrogen in the grain were about the same whether cured slowly or rapidly.

There are indications that there was some translocation of materials from the straw to the grain when oats was cut when the kernels of the terminal spikelets were in the thick milk stage (seven days early) and none when cut at maturity. For wheat there are no indications of translocation when cut at the time the terminal spikelets were in the hard dough (seven days early).

This difference in the results for the two crops may have been brought about to some extent by the slightly higher moisture content in the oat kernels harvested seven days early and the marked higher moisture content in the straw for all stages as compared with the moisture content of the same parts for wheat. While there was enough moisture present in all parts of the wheat plant up to within a day or two of maturity to permit translocation of materials to go on, the larger amounts present in the oat plants cut on the same day would undoubtedly result in the moisture remaining above the necessary point for a longer time in oats than in wheat under the slow drying conditions.

SUMMARY

Subject to the environmental conditions under which this work was done, the following results are indicated:

1. Cutting wheat and oats before they were mature resulted in reduction in yield when the harvested grain was cured in the shock. There was a tendency for straw yields to be lower from the cutting made nine days early as compared with that made at maturity. Results over a period of years are necessary in order to come to conclusions regarding how immature grain can be cut without resulting in material reduction in yield.

2. Lower weight per bushel resulted from premature cutting. There was not enough reduction in weight per bushel for wheat cut when the terminal spikelets were turning color and the kernels in them were in the hard dough (seven days early) and for oats cut when the kernels in the terminal spikelets were in the thick milk stage (seven days early) to make any change in the market grade as compared with the same grains cut at maturity.

3. There was an increase in weight per 1,000 kernels for wheat harvested up to the time the kernels in the lower spikelets were in the medium hard dough (three days early) and for oats up to the time the kernels in the terminal spikelets were in the hard dough stage (four days early).

4. Cutting seven days early resulted in a comparatively large percentage of green kernels in wheat and a still higher percentage in oats. The green color disappeared entirely from wheat and to a very considerable extent from oats when cured slowly in the shock.

5. The percentage of hulls of oats cut before maturity was higher than when cut at maturity.

6. Failure of the yields per acre, weights per bushel, and weights per 1,000 kernels of wheat and oats cut at early stages of maturity and cured in the shock to approach that cut at later stages indicates that materials were not translocated to any extent from the straw to the grain after cutting.

7. Weights per 1,000 kernels from the various cuttings were as great when dried rapidly in the oven as when cured slowly in the bag or shock. This is additional evidence that translocation of materials did not take place to an extent that would influence yield.

8. Hull percentages in oats cut at any stage were as high when dried rapidly in the oven as when cured slowly in the shock. This indicates that materials stored temporarily in leaves and stems was not moved into the grain in large enough quantities to lower the percentage of hull appreciably.

9. Higher nitrogen content of the straw from wheat and oats cut seven days early and dried rapidly in the oven as compared with slow drying in the shock where leaching could not occur indicates that nitrogen was moved out of the straw.

10. The nitrogen content of the grain of oats cut seven days early and cured in the shock increased somewhat as compared with that dried rapidly in the oven. No increase occurred for wheat.

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RELATION OF SELFED STRAINS OF CORN TO F_1 CROSSES BETWEEN THEM[1]

GUNNAR NILSSON-LEISSNER[2]

INTRODUCTION

The use of inbred strains of corn for the production of single and double crosses and synthesized varieties is at the present time a commonly accepted method of corn breeding. A thorough knowledge of the relation between the inbred strains and the F_1 crosses between them, therefore, is of great importance. As yet comparatively few experiments have been published that deal with this question. Kiesselbach (3)[3] has found F_1 crosses between high-yielding corn strains to be, as a rule, better yielders than those between low-yielding strains, while Richey (5) and Richey and Mayer (6) were unable to find any such general relation. Hayes (2) sums up the present knowledge of this problem thus, "It seems reasonable to conclude that crosses between higher yielding strains should, as a general rule, be of greater value than crosses between low-yielding strains," and adds also that further extensive experiments are needed. The present investigation, therefore, was planned by him and all the crosses were made at the Minnesota Experiment Station in 1925. In the spring of 1926 the writer took over the material and has carried out the experiments and calculations during the year in which he has been a member of the plant breeding department of the University of Minnesota.

MATERIALS AND METHODS

Twenty-three selfed lines of corn and the F_1 crosses between them have served as material for this investigation. The inbred strains were picked out because they appeared to be the best and most vigorous ones so far obtained at University Farm. One of the purposes of the experiment was to find out which selfed lines combined best in F_1 crosses. Crosses were made so as to include all possible combinations of dent strains and all possible combinations of flint

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[2] Sveriges Utsädesförening, Svalöf, Sweden. The writer wishes to express to Dr. H. K. Hayes and Dr. H. E. Brewbaker, Minnesota Agricultural Experiment Station, his appreciation for the material and facilities furnished him in connection with this work and also for valuable suggestions and criticisms in preparing this paper. Thanks are also extended to the International Education Board which has made possible this investigation.

[3] Reference by number is to "Literature Cited," p. 453.

strains. A comparison was also made between the selfed lines and strains of the same lineage in 1924 followed by sib-mating in 1925. Fourteen of the strains were from dent varieties, four from Minnesota No. 13 (Nos. 11 to 14), six from Rustler White dent (Nos. 15 to 20), and four from Northwestern dent (Nos. 21 to 24). The nine other strains were flint corn, including four from Longfellow flint (Nos. 25 to 28), two from King Phillip flint (Nos. 29 and 30), two from Squaw flint (Nos. 31 and 32), and one from Red Flint (No. 34). The strains had been selfed between 4 and 17 years (Table 1).

The material was planted in the spring of 1926 at UniversityFarm, St. Paul. Five seeds were planted per hill, the hills were 3½feet apart each way, and there were 15 hills in each row. Each plat consisted of one such row and, as a rule, as far as the seed supply permitted, each line or F_1 cross was replicated once. A selfed line and the sib-pollinated strain from the same selfed line were planted in adjacent rows. The different lines were separated by border rows, consisting in the selfed and sib-pollinated material of bulked selfed strains of Minnesota No. 13 and in the F_1's of normal Minnesota No. 13. The same material also was used to plant border hills at both ends of the rows. There were 23 selfed, 23 sib-pollinated, and 113 cross-pollinated lines in series I, and 18 selfed, 21 sib-pollinated, and 84 cross-pollinated lines in series II.

When the plants were about 2 feet high they were thinned to a stand of three plants per hill and only two- or three-plant hills surrounded on all sides by two- or three-plant hills were harvested. As a result of the unusually dry weather in the earlier part of the summer the germination was somewhat poor. In some hills germination was delayed for about three weeks as compared with other hills in the same row. Height of plant was determined in the field by measuring 10 plants from 10 different hills (if possible) of each plat. From the harvested hills all ears were taken, but the lower ear of each plant, when such were obtained, was kept separate from the upper ear. Measurements were made only on upper ears. Yield, however, was determined from all the ears of a plat. The ears were dried to a water content of about 2 to 4%, weighed, and measured. The corn then was shelled and the cobs weighed again. Yield figures indicate the dried, shelled corn per hill. In all, about 11,500 ears were used for the investigation. The yields and measurements are all given in terms of the mean for the plat.

Due to the above-mentioned uneven germination and the fact that it was delayed for some reason, considerably more in the second series than in the first, no averages of the two series were computed.

The period of maturity in the second series was delayed to such an extent that the border rows, every fifth of which was harvested as a check plat, could not be used for correcting the yields in the two series for soil heterogeneity. The border rows were among the most immature ones and for this reason could not be used to adjust the yields of other plats.

COMPARISON OF SELFED AND SIB-POLLINATED STRAINS

It was thought desirable for the purpose of the investigation to make an estimation of the homogeneity of the inbred strains. Six different characters measured in the selfed and the sib-pollinated strains, therefore, are compared in Table 1. The values given in this case are averages of series I and II, as the variability and the differences between the two series seemed to be rather small in these lines. No. 17 sib-pollinated and Nos. 21, 23, 24, 25, and 28 selfed were not replicated and, therefore, values were calculated for the yield of these strains in the second series on the basis of relative yielding ability of strains grown in both series in relation to the yield of these strains in the first series.

TABLE 1.—*Comparison between selfed and sib-pollinated strains.*

No.	Years Selfed	Years Sib-pollinated	Height of plant, inches	Ears Length, cm.	Ears Diameter, cm.	No. of rows	Yield per hill, grams	Percentage of second ears
11	5	–	66.0	11.90	3.97	14.23	120	4
11	4	1	68.3	11.19	3.67	14.69	84	8
12	6	–	60.4	11.13	4.12	17.68	133	10
12	5	1	61.1	8.90	4.12	17.45	113	9
14	11	–	59.0	9.94	3.11	15.34	83	20
14	10	1	58.6	10.19	3.13	14.50	100	26
15	6	–	73.7	12.54	3.26	12.29	132	15
15	5	1	69.3	13.45	3.40	12.80	125	53
16	6	–	60.8	13.20	4.03	15.89	130	13
16	5	1	62.2	11.87	3.39	12.85	108	6
17	7	–	70.4	10.76	3.85	12.43	173	19
17	6	1	64.5	9.73	4.03	12.25	150	0
18	7	–	59.9	9.81	3.99	14.68	80	12
18	6	1	63.2	10.04	4.11	14.84	94	21
19	8	–	74.6	11.56	3.67	11.13	97	10
19	7	1	87.0	13.02	3.88	12.25	177	11

TABLE 1.—*Continued.*

No.	Years Selfed	Years Sib-pollinated	Height of plant, inches	Ears Length, cm.	Ears Diameter, cm.	No. of rows	Yield per hill, grams	Percentage of second ears
20	7	–	69.0	7.83	3.78	13.60	53	22
20	6	1	67.9	8.42	3.32	12.67	57	33
21	7	–	63.0	11.50	3.40	10.00	205	0
21	6	1	63.5	11.33	3.38	11.43	149	19
22	7	–	64.7	11.09	3.62	13.69	66	15
22	6	1	69.7	14.26	3.68	12.99	123	8
23	7	–	72.0	9.28	3.17	11.20	47	33
23	6	1	76.0	11.13	3.19	10.35	104	9
24	7	–	59.9	14.36	3.29	9.27	143	0
24	6	1	61.2	14.12	3.28	9.29	130	6
25	7	–	60.3	14.26	2.94	8.00	106	19
25	6	1	63.4	14.07	2.68	8.00	94	0
26	4	–	61.5	15.93	2.48	8.00	183	42
26	3	1	60.3	15.61	2.77	8.05	205	48
27	4	–	74.1	13.69	2.80	8.00	170	47
27	3	1	62.2	13.31	2.56	7.10	137	32
28	7	–	45.0	13.20	2.96	8.00	28	0
28	6	1	47.5	11.75	2.74	8.00	59	23
29	7	–	61.8	10.75	2.63	8.00	56	0
29	6	1	63.6	10.52	2.68	8.04	57	0
30	7	–	70.9	18.03	3.09	9.22	180	21
30	6	1	70.7	17.26	2.99	8.70	120	13
31	6	–	45.5	11.10	2.82	8.84	49	0
31	5	1	49.3	10.83	2.88	8.28	58	23
32	8	–	48.9	11.57	3.17	10.39	73	7
32	7	1	48.3	12.21	3.38	10.34	78	0
34	17	–	55.6	13.03	2.95	8.00	104	23
34	16	1	57.5	12.38	2.82	7.79	87	19

A brief consideration of the material presented in Table 1 makes it obvious that no very large differences exist between the selfed and the sib-pollinated lines. Nos. 14 and 34 that have been selfed for 11 and 17 years, respectively, show very small differences between selfed and sib-pollinated plats except concerning yield. The yield figures are, however, rather variable in this material—similar differences can be found in Nos. 11, 21, 22, 26, and 30—and most probably these differences do not mean anything. In three cases—Nos. 18, 19, and 23—the sib-pollinated plat seems to be more vigorous than the selfed, as all characters have higher values in the former than in the latter. In two other cases—Nos. 17 and 27—the reverse condition seems to prevail. By Student's method (8) the chances are found that there is a real difference for each character between the lines selfed four, five, or six years and the corresponding sib-pollinated strains and also between the lines selfed seven or eight years and the corresponding sib-pollinated strains. In Table 2 the obtained values of Z and the odds are presented. It should be noticed that the odds in only two cases approach a value that commonly is considered as significant and in no case can be designated as highly significant. There does not seem to be much more variability in the lines selfed four, five, or six years than in those selfed seven or eight years. This test does not prove whether in any single case there really is a significant difference between a selfed line and the corresponding sib-pollinated strain. If a significant difference had been found by this method it would have meant that there is a consistent superiority of the sib-pollinated strains over the selfed or the reverse. When such a result was not obtained, no absolute statement can be made. It may be concluded, however, that in general these inbred strains are fairly homozygous in respect to factors concerning the characters under investigation. The behavior of the selfed line planted side by side with the F_1's in the field thus ought to give a fair indication of the behavior of the parents of the crosses, even if these belonged to the last preceding generation.

TABLE 2.—*Odds calculated by Student's method that there are real differences concerning certain characters between the selfed and the corresponding sib-pollinated strains.*

	Height of plant		Ears Diameter		Yield	Percentage of second ears
		Length	Diameter	No. of rows		
Lines selfed 4, 5, or 6 years............. Z	0.2780	0.6889	0.3390	0.5000	0.0291	0.0203
Nos. 11, 12, 15, 16, 26, 27, 31............Odds	2.8:1	13.0:1	3.5:1	6.5:1	low	low
Lines selfed 7 or 8 years............. Z	0.4988	0.2381	0.0889	0.0606	0.0040	0.0061
Nos. 17–25, 28, 29, 31, 32...............Odds	17.3:1	3.6:1	low	low	low	low

A COMPARISON OF F_1 COMBINATIONS

In Tables 3 to 6 the yields of all the different crosses are presented in such a way that it will be possible to find out which of the selfed lines combine the best in the F_1 crosses. The breeding numbers of the parental lines are given in the margins above and to the right. The yield of any particular cross is found in the row and column corresponding to the numbers of its male and female parents. For example the yield of the cross No. 14 x No. 24 is found in Table 3 in the column of No. 14 and in the row of No. 24 and is 138 grams per hill. The yield of No. 14 selfed is found in the column for selfed to the right of the figure 14 in the number column and is 125 grams per hill. In the next column to the right is found the average yield of all crosses with the respective lines. For No. 14 this average is 313 grams per hill. The selfed lines are arranged in order of their yielding ability as shown by the trials in the two series, beginning with the best yielder to the left and at the top of the table. As all possible combinations were not available and as especially in the second series several crosses are missing, these averages are not quite conclusive for judging the average yielding ability of crosses in relation to certain selfed lines. In the case of the flints, where in both series a marked correlation between the average yield of each two parental selfed strains and of the F_1 crosses is obtained, a definite relationship appears fairly conclusive.

TABLE 3.—*Yields in grams per hill of selfed lines and crosses of dent corn, series I.*

														Yield	
15	17	12	24	16	14	11	19	18	20	22	21	23	No.	Selfed lines	Average of F_1 crosses
	371	320		363	327	402	237	420	306	340	414		15	181	350
		185	368	325	414	358	378	180	365	351	229	319	17	173	320
			300	299	318	329	372	376	348	342	383	311	12	163	324
					138	247		289	298		226	284	24	143	269
					280			326	286		324	274	16	140	310
						345	349	407	323	340	336	183	14	125	313
							458	407	360	349		318	11	114	357
								354	167	267	362	323	19	113	322
									289	284	277	262	18	110	323
										283		285	20	100	301
											279	250	22	74	309
												208	21	57	304
													23	47	274

TABLE 4.—*Yields in grams per hill of selfed lines and crosses of dent corn, series II.*

11	21	16	12	17	24	15	19	22	20	18	14	23	No.	Yield Selfed lines	Yield Average of F_1 crosses
			277	417	279	351	377	374	366	331	316	291	11	126	338
		242	286	269	260	271		338		299	265		21	125	279
			277	281		311			309	266	248	261	16	119	274
				231		259	369	314		300	235	264	12	102	281
						308	331	322	333	107		305	17	100	290
									278	268	311	258	24	87	276
							233	355	247				15	82	292
								324	168	372	300	311	19	80	309
									276	282	308	236	22	58	313
										312	243	285	20	53	282
													18	50	282
													14	41	278
													23	29	276

TABLE 5.—*Yields in grams per hill of selfed lines and crosses of flint corn, series I.*

26	27	30	34	25	32	29	31	28	No.	Yield Selfed lines	Yield Average of F_1 crosses
		361		263	357	359		323	26	235	333
		403	362		326	346	259	256	27	227	325
			397	349	382	318	377	332	30	222	365
				297	340	346	315		34	129	343
					321	219	298	233	25	106	283
						296	274	299	32	79	324
							232		29	78	302
								233	31	53	275
									28	28	279

TABLE 6.—*Yield in grams per hill of selfed lines and crosses of flint corn, series II.*

30	26	27	34	32	25	31	29	28	No.	Yield Selfed lines	Yield Average of F_1 crosses
	361	311	268	304	297	301	285		30	138	304
				324	326			288	26	130	325
			330			234	242	245	27	113	272
				247			245		34	79	273
					266	241	259		32	66	274
						286	197	218	25	65	265
							240		31	45	260
									29	34	245
									28	17	250

In the dents it is not as easy to find a marked correlation similar to the one in the flints just mentioned. The order of the selfed strains of dents in the two series is very different, whereas in the flints only small differences in this respect will be found. The differences in reaction between the dents and flints at first seems rather surprising, but it may be explained in a rather simple way as will be made clear later. Even among the dents some strains can be shown to be, on an average, more satisfactory parents for making F_1 crosses than others. For example, the crosses with Nos. 11, 15, and 19 in both series are generally good yielders, while Nos. 21, 23, and 24 usually give rise to low-yielding crosses. It is of particular interest that No. 24 yields fairly well when selfed, but does not combine especially well with any other strain. It is apparent that in general the better yielding lines are more satisfactory as parents for producing F_1 crosses than the lower yielding selfed lines.

CORRELATIONS BETWEEN CERTAIN CHARACTERS OF SELFED LINES AND F_1 CROSSES

Correlations between several characters of the selfed lines and the same characters of the F_1 crosses have been worked out. In these cases the average of each two parental lines was correlated with the F_1. Some other writers, notably Richey and Mayer (6) and Love and Wentz (4), in similar investigations, have correlated the characters of the pistillate parents with those of the crosses. Considering that the characters concerned are each dependent upon several factors and that the staminate parent has just as much influence on heredity as the pistillate one, it was thought more reasonable to use the average of the parents in this work. Calculated yields were obtained for the second series for lines Nos. 21, 23, 24, 25 and 28 on the basis of the yield in the first series and the relative yield of those strains which were grown in both series.

At first the correlations were worked out for all the plats in each series, taking dents and flints together in the same table. When each group was studied separately, differences between the two types of corn were found so that the correlation between yield of shelled corn of parents and of F_1's was ±0.1852 in the dents and ±0.7431 in the flints, while the corresponding correlation of percentage of second ears was ±0.1521 in the dents and ±0.8167 in the flints. It was considered desirable, therefore, to calculate all correlations for dents and flints separately. The computed coefficients of correlation are given in Table 7. Where the dents and flints seem to react in the same way the values of the coefficient of correlation calculated from both dents and flints also are given. The combined values for each correlation for series I and series II have been calculated by the method of combining values from small samples given by Fisher (1).

Positive correlation coefficients were obtained in all cases for the yield of the inbred parental lines with the yield of the F_1's between them. While the flints gave high and significant coefficients of about

TABLE 7.—*Coefficients of correlation between certain characters of the selfed lines and the same characters of the F_1 crosses.*

Characters correlated	Series Group	Number of entries	Coefficient of correlation	Difference
Yield, grams per hill	I Dent	70	+0.1847±0.0779	
	I Flint	30	+0.7098±0.0611	0.5251±0.0990
Yield, grams per hill	II Dent	59	+0.1857±0.0848	
	II Flint	23	+0.7834±0.0544	0.5977±0.1007
Yield, grams per hill	I Dent	70	+0.1847±0.0779	
	II Dent	23	+0.1857±0.0848	0.0010±0.1151
Yield, grams per hill	I & II Dent	93	+0.1852±0.0580	
Yield, grams per hill	I Flint	30	+0.7098±0.0611	
	II Flint	23	+0.7834±0.0544	0.0736±0.0818
Yield, grams per hill	I & II Flint	53	+0.7434±0.0427	
Length of ear	I Dent	70	+0.3677±0.0697	
	I Flint	30	+0.5501±0.0859	0.1824±0.1106
Length of ear	II Dent	59	+0.3726±0.0756	
	II Flint	23	+0.6476±0.0814	0.2750±0.1112
Length of ear	I Dent & flint	100	+0.7311±0.0314	
	II Dent & flint	82	+0.6904±0.0355	0.0407±0.0474
Length of ear	I & II Dent & flint	182	+0.7347±0.0232	
Diameter of ear	I Dent	70	+0.7287±0.0378	
	I Flint	30	+0.7234±0.0588	0.0053±0.0699
Diameter of ear	II Dent	59	+0.7065±0.0439	
	II Flint	23	+0.6751±0.0766	0.1686±0.0883
Diameter of ear	I Dent & flint	100	+0.9171±0.0107	
	II Dent & flint	82	+0.9124±0.0125	0.0047±0.0165
Diameter of ear	I & II Dent & flint	182	+0.9150±0.0082	
No. of kernel rows	I Dent	70	+0.7203±0.0388	
	I Flint	30	+0.3845±0.1050	0.3358±0.1118
No. of kernel rows	II Dent	59	+0.8715±0.0210	
	II Flint	23	+0.8000±0.0506	0.0715±0.0548
No. of kernel rows	I Dent & flint	100	+0.9260±0.0096	
	II Dent & flint	82	+0.9617±0.0056	0.0357±0.0111
No. of kernel rows	I & II Dent & flint	182	+0.9457±0.0053	
Percentage 2nd ears	I & II Dent	42	+0.1521±0.1017	
Percentage 2nd ears	I & II Flint	18	+0.8167±0.0529	0.6646±0.1146
Height of plant	I Dent	70	+0.5447±0.0567	
	I Flint	30	+0.4538±0.0978	0.0909±0.1130
Height of plant	II Dent	59	+0.7991±0.0318	
	II Flint	23	+0.6762±0.0764	0.1229±0.0828
Height of plant	I Dent & flint	100	+0.6902±0.0353	
	II Dent & flint	82	+0.7974±0.0271	0.1072±0.0445
Height of plant	I & II Dent & flint	182	+0.7456±0.0224	

+0.7 (Table 8), the correlations in the dents were rather low and hardly significant when considered separately. When combined, the coefficient of correlation in the latter group is +0.1852 ±0.0580, which is probably significant. This difference in correlation between the dents and the flints is, as already mentioned, rather unexpected. There does not seem to be any reason why the yielding ability should be expressed or inherited in a different way in the two groups. The nature of the material used probably can explain part of the discrepancies. The variation in yield among the flint strains is larger than in the dents, therefore, the chance deviations from the regression line in the first group mentioned will decrease the value of the coefficient of correlation less than in the latter group. Another probable cause of the low correlation in the dents is the abnormal weather conditions during the 1926 season. Due to delayed germination and also to the very abundant precipitation in the latter part of the season, many of the F_1 crosses did not completely mature before the first killing frost. In this respect the dents seemed, in general, to have suffered more than the flints, all of which matured comparatively well.

In the dent corn there is a lower correlation in length of ear between parents and F_1's than there is in the flints. The differences, however, are hardly significant even if the tendency is very much the same in both cases (Table 9). The higher coefficient of the flints probably can be accounted for, at least partly, by the larger variability of this group in respect to ear length. When both groups are combined, a coefficient of about +0.7 is obtained.

TABLE 8.—*Correlation surface for the average yield of each pair of parental lines and yield of the corresponding F_1 generations of flint corn, series I.*

Classes for yield of parental lines	Classes for yield of F_1 Crosses											
	210	230	250	270	290	310	330	350	370	390	410	Total
50		1			1							2
70		2		1	1							4
90	1				2		1					4
110					1							1
130			1				2		1			4
150			1			2		5		1		9
170				1				1	1	1		4
190												0
210												0
230									1		1	2
Total	1	3	2	2	5	2	3	6	3	2	1	30

$r = +0.7098 \pm 0.0611$

The coefficients of correlation of diameter of ears of parents and F_1 generations are in both series and for flints as well as for dents practically the same or about +0.7. When flints and dents are combined in one table a coefficient of about +0.9 is obtained. This is due to the fact that all flints have smaller diameters and that the two separate tables, when put together, do not overlap at all and

TABLE 9.—*Correlation surface for the average length of ears of each pair of parental lines and length of ears of the corresponding F_1 generations of dent corn, series I.*

Classes for ear length of parental lines	11.2	11.75	12.25	12.75	13.25	13.75	14.25	14.75	15.25	15.75	16.25	16.75	17.25	17.75	18.25	18.75	Total
	Classes for ear length of F_1 crosses																
9.75											1	1					2
10.25						1		3		2	1	1					8
10.75	1				1	1	1		2	4	1		2	1			14
11.25								3	5	1	4	1		1	1		16
11.75									4	1	3	3	1	1	1		14
12.25								1			1	3	3		1	1	10
12.75										2			1	1			4
13.25									1					1			2
	1	0	0	0	1	2	1	7	12	10	11	9	7	5	3	1	70

$r = +0.3677 \pm 0.0697$

thus make the swarm of individuals in the combined correlation surface relatively more elongated.

Judging from the correlation surfaces and coefficients, number of kernel rows in the ear behaves very much the same in this material as does the diameter of ears. The separate coefficients are about +0.7 to +0.8, except for flint corn in series I where the low coefficient of +0.38 was obtained. The lower relation in the flints undoubtedly is due to the very small variability of this character in the group concerned. The combined coefficient for flints and dents in the first series is given, therefore, even though the difference between the separate coefficients is about three times its probable error. The dents and flints combined produce the same sort of result as was obtained for diameter of ears. The calculated coefficient of correlation for the average of the two series is about +0.9. The difference between the two coefficients of correlation in series I and II is about three times its probable error, $+0.0357 \pm 0.0111$, but as the first decimal is the same in both cases and differences in the later decimals are of small interest in this investigation, the two coefficients have been combined and a generalized coefficient of $+0.9457 \pm 0.0053$ obtained.

The coefficients of correlation for the percentage of second ears in the selfed lines and in the F_1 crosses between them are, as already mentioned, very different in the dents and flints. As this percentage seems to be very much influenced by environmental factors, a correlation computed from only one series of plats would not be of very much value. For this reason the data from the two series were averaged with the hope of obtaining more conclusive figures for the calculation. Only strains that were grown in both series could be included. The lower correlation in the dents can be accounted for partly by the fact that the range in variation of this character in the dent group is only about half that in the flint group.

The correlations concerning the character height of plant are all positive and significant, but somewhat higher in the second series than in the first. The difference between the coefficient for series I and that one for series II approaches significance but is of no importance so far as this investigation is concerned.

MULTIPLE CORRELATIONS

There is another way in which the influence of the parental lines upon the F_1 crosses may be calculated and this is to work out the multiple correlations, for example, between yield of the F_1 crosses and all important characters of the parental lines. Such a multiple correlation coefficient (R) then will express to what extent the F_1 yield is influenced by the sum of the variability of the considered characters of the parents. Two R's have been calculated, one for flint and the other for dent corn, in series I. In these cases, as in computing the other correlations, the averages of each two parental lines for each character have been used for correlating with the other averaged characters of these lines and with the yield of the F_1 crosses. The characters chosen were yield (b), length of ear (c), number of kernel rows (d), percentage of second ears (e), and height of plant (f) of the parental lines and yield of the F_1 crosses (a). The multiple correlation coefficients were for the dent corn strains $R_{a.bcdef} = +0.6687$ and for the flints $R_{a.bcdef} = +0.8240$. These coefficients may be substituted in the formula $100\ (1 - \sqrt{1-R^2})$, thus giving a direct measure of the degree to which the variation in yield of the F_1 crosses is a function of the parental characters considered. In the dent corn crosses about 25% of the variability in yield is accounted for by the variation of the above-mentioned characters of the selfed parental lines. In the flint corn crosses about 43% of the variability in yield is due to these factors. ·Considering that the coefficients were obtained from comparatively small and not replicated plats in a field where there apparently existed a certain variation due to soil heterogeneity, these results are surprisingly good. They undoubtedly indicate that, if all environmental factors causing variation in yield in different parts of the field could have been eliminated, an even higher percentage of the yield variability would have been accounted for by the variation of the measured characters of the parents.

Some of the simple correlations worked out for the purpose of obtaining the multiple correlations are worth mentioning. Thus, the correlations between yield and length of ears in the averages of each two groups of selfed lines were positive and significant, *viz.*, +0.9592 ±0.0065 in the dents and +0.7357 ±0.564 in the flints. This is in accordance with results obtained by Richey and Willier (7), Hayes (2), and others. Insignificant coefficients in both groups were obtained for the correlation between yield and number of kernel rows in the selfed lines, whereas the correlation between yield and percentage of second ears was +0.8563 ±0.0329 in the flints and —0.6456 ±0.0470 in the dents, showing the different behavior of the two groups. The simple correlations of length of ear, number of kernel rows, percentage of second ears, and height of plant of the parental lines with yield of the F_1 crosses were all positive and significant, except the correlation percentage of second ears of the parents with yield of the F_1 crosses in the dents, which was negative but low and insignificant.

DISCUSSION

Richey (5) has found some tendency for the F_1 crosses in corn having one parent in common to react similarly. This relationship has also been studied (Tables 3 to 6). From this material it appears that, in general, the relationship is a direct result of the correlation of the expression of a character in the parental selfed strains and in the offspring. As a natural consequence of this relationship, a correlation between the average of the parents and the F_1, as shown in Table 7, would be expected. It can be stated, as a general result of this investigation, that as a rule high correlations have been found to exist between yield and other characters that are expressions of vigor in the selfed lines and the same characters in the F_1, crosses between them. This is just what should be expected on the basis of modern conceptions of heredity and hybrid vigor. It is a well-known fact that in certain cases a single genetic factor conditioning such characters as golden plant, dwarf and brachytic, when in the homozygous recessive condition, becomes of major importance in limiting the vigor and yielding ability. Such cases would no doubt prove to be exceptions to this general rule.

For the practical plant breeder these relations, if they prove to be general, will be of much value as they enable him to plan better for his crosses. Even if there are chances to get good vigorous F_1 generations of corn by crossing two low-yielding selfed lines, this does not appear to justify the procedure. Judging from the evidence of the above-related correlations, it seems to be advisable to select in the selfed lines for the characters that are desired and to use only the most vigorous strains for the crosses.

SUMMARY AND CONCLUSIONS

The relation between 22 selfed lines of corn and 100 F_1 generations of crosses between them has been investigated. The lines had been selfed from 4 to 17 generations and from a comparison with brother-sister mated strains of the same descendance they appeared to be fairly homozygous. Certain lines, when mated with any one of the other strains, on an average, gave high-yielding F_1's, while others gave low-yielding F_1's.

Correlations between the average expressions of certain characters in the two parental lines and the expressions of the same characters in the F_1 generations have been computed as indicated below.

Characters studied	Dent corn	Flint corn	Average of dent and flint corn
Yield	+0.1852±0.0580	+0.7434±0.0427	
Length of ear			+0.7347±0.0232
Diameter of ear			+0.9150±0.0082
Number of kernel rows			+0.9457±0.0052
Percentage of second ears	+0.1521±0.1017	+0.8167±0.0529	
Height of plant			+0.7456±0.0224

Multiple correlations of yield of F_1 crosses in relation to the yield, length of ear, number of kernel rows, percentage of second ears, and height of plant of the average of each two parental lines were calculated in series I for dent and flint corn strains separately. In the dent corn the coefficient was +0.6687, in the flint corn +0.8240. These multiple correlations account for about 25% of the variability in yield of the dent corn crosses and about 43% of that of the flint corn crosses. If soil heterogeneity had been eliminated, still higher percentages could have been expected.

The results presented here have demonstrated that in material of this nature selection among the selfed lines for the characters desired is of value and that crosses between the more vigorous selfed lines yield better, on the average, than crosses between less vigorous lines.

It is concluded, therefore, that selection of the most vigorous selfed lines for the production of F_1 single or double crosses and synthesized varieties is desirable. The only method of learning the better F_1 combinations is by actual trial.

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TASSELING AND SILKING AS CRITERIA OF COMPARATIVE EARLINESS IN CORN[1]

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Tasseling and silking are fairly definite and determinate phenomena. This is especially true of silking. While a considerable period elapses between the first appearance of the tassel and its full protrusion, if a plant be described as tasseled as soon as anthers have begun to protrude, then the tasseling stage also can be said to be rather sharply defined. Varieties or strains of corn which are compared as to the amount of tasseling or silking found in each are therefore measured quantitatively. Estimate and the accompanying personal equation are very largely eliminated when this criterion is used. This can not be said of comparisons based upon description of the stage of development of the ear. Milk, dough, dent, glazed, and ripe stages merge one into the other, and it is not possible to classify accurately all ears on the basis of such stages. Such classification is no doubt sufficiently accurate if based on a very large number of observations, but the method is at best a cumbersome one.

It is evident that counts of tassels and silk would furnish a very convenient measure of comparative earliness, provided they were closely correlated with it. The investigation herein reported was planned and carried out for the purpose of learning whether or not such close correlation exists.

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NATURE AND SOURCE OF THE DATA

Twenty-three varieties are represented by the data reported. They are the varieties included in the corn variety test project carried on at the North Dakota Agricultural Experiment Station at Fargo. The corn was planted May 24 on land which was apparently uniform and as good for experimental purposes as can ordinarily be obtained. It had been in corn the previous year. The soil was a typical Fargo clay. Four rows of each variety were planted, each row consisting of 54 hills. The data were taken from the middle pair of rows from each of which two hills at each end were excluded. The plats were not replicated.

The season was cool and consequently unfavorable for corn. Many varieties which reach full maturity in average years did not mature. The earlier varieties reached full maturity.

The method of taking the tasseling and silking data was as follows: As soon as tasseling and silking began counts were made of all plants tasseled and silked in each variety. These counts were recorded separately for tasseled plants and silked plants. At first such counts were repeated at intervals of two days. As the season advanced, however, it became impossible to complete the work in this period of time and in a few instances as many as five days elapsed between successive counts. As suggested above, plants were regarded as tasseled when anthers had begun to protrude from the florets. The taking of these data covered a period extending from July 24 to August 30.

When the above-described record was complete, the data were collected and analyzed so as to show the following for each variety: (1) The date on which the first tassels and first silks, respectively, appeared in each variety; (2) the date on which one-fourth of the plants were tasseled and silked, respectively; (3) the date on which one-half the plants showed the corresponding condition; and finally (4) the date on which each variety was fully tasseled and silked, respectively. In those cases in which the desired stage was reached somewhere between the dates upon which counts were made the date of such stage was derived by interpolation. The rank of each variety on the basis of these criteria was then determined. This ranking is shown in Table 1.

Notes were also taken on the condition of the ears as to maturity. These were taken on the following dates: August 28, September 2, September 15, September 23, and September 29. These data were taken on every fifth hill in one row of each variety, and from the record of these observations the average condition of each row was

TABLE I.—*Rank of 23 varieties of corn as to earliness on the basis of various criteria.*

Variety	Criteria													
	Percentage dry matter	Percentage dry matter (re-calculated)	Date first tassels	Date ¼ tasselled	Date ½ tasselled	Date fully tasselled	Date first silks	Date ¼ silked	Date ½ silked	Date fully silked	Stage maturity of ears, Sept. 15	Stage maturity of ears, Sept. 23	Stage maturity of ears, Sept. 29	Average of tassel, silk, and ear criteria[a]
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Howes' Alberta	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	4.5	1.0
Assiniboine	2.0	2.0	2.0	2.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.5	4.5	2.2
Dakota White	3.0	4.0	5.0	3.0	2.5	2.5	7.0	3.5	3.0	3.5	5.0	5.0	4.5	3.5
Pioneer	4.0	4.0	5.0	6.0	6.5	6.5	7.0	5.5	4.0	5.5	10.0	10.5	4.5	6.8
Gehu	5.0	4.0	3.0	4.0	4.5	4.0	7.0	3.5	5.5	3.5	4.0	2.5	4.5	3.9
Shota	6.0	6.0	5.0	5.0	4.5	5.0	2.5	5.5	5.5	5.5	3.0	5.0	4.5	4.9
Square Deal	7.0	7.0	5.0	7.5	9.0	9.0	7.0	9.0	10.0	7.5	6.5	5.0	4.5	7.9
Northwestern (Will)	8.0	8.5	12.5	11.5	9.0	10.5	15.5	9.0	8.0	11.0	13.0	7.5	9.0	9.9
Falconer	9.0	8.5	5.0	7.5	6.5	6.5	7.0	9.0	10.0	11.0	6.5	7.5	4.5	8.1
Northwestern (Amenia)	10.0	10.0	12.5	10.5	13.0	14.0	15.5	9.0	10.0	14.5	8.0	10.5	11.0	11.3
Mandan King	11.0	11.0	17.0	11.5	11.0	8.0	11.0	18.0	17.0	11.0	11.5	9.0	12.0	12.1
Burda	12.0	12.5	12.5	11.5	17.0	19.5	15.5	14.5	17.0	16.5	20.0	19.5	18.5	16.9
Minnesota No. 23	13.0	12.5	12.5	11.5	9.0	14.0	7.0	9.0	7.0	7.5	16.5	13.0	10.0	10.9
Minnesota No. 13 (Golden Moccasin)	14.0	14.0	20.0	16.5	17.0	17.0	15.5	19.0	13.0	19.5	11.5	15.0	14.5	16.1
Payne's	15.0	15.0	12.5	16.5	13.0	10.5	15.5	14.5	13.0	11.0	18.5	19.5	14.5	14.6
Minnesota No. 13 (Haney)	16.0	17.0	20.0	16.5	17.0	17.0	15.5	14.5	17.0	14.5	18.5	16.5	14.5	16.4
Soviet	17.0	17.0	12.5	19.0	21.0	19.5	7.0	14.5	17.0	16.5	9.0	16.5	20.0	16.6
Wisconsin No. 25	18.0	17.0	12.5	11.5	17.0	17.0	15.5	14.5	17.0	18.0	14.5	13.0	18.5	15.3
Mercer	19.0	19.0	20.0	20.0	17.0	12.0	20.0	20.0	20.0	19.5	14.5	18.0	17.0	17.6
Rustler	20.0	20.0	12.5	16.5	13.0	14.0	15.5	14.5	13.0	11.0	16.5	13.0	14.5	13.9
All Dakota	21.0	21.5	20.0	21.5	21.0	22.0	21.5	21.5	21.0	21.0	21.0	21.0	21.0	21.2
Golden Glow	22.0	21.5	20.0	21.5	21.0	21.0	21.5	21.5	22.0	22.0	23.0	22.0	22.0	21.8
Rainbow	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	22.0	23.0	23.0	22.9

[a] Columns 4, 8, and 14 omitted from this average.

determined and described for each of these dates. The varieties were then ranked as to maturity according to these determinations. This ranking is given in Table 1 for the three dates September 15, September 23, and September 29. The data taken on the earlier dates did not record anything but very large differences. They particularly failed to show differences between members of the group of later varieties.

As a final criterion, there was available a determination of the percentage of dry matter in the ears of each variety. Since this determination was primarily for the purpose of assisting in the calculation of yields, it was made at the time of harvest. Harvest was made on two dates, September 25 for an earlier and October 15 for a later group of varieties. In arriving at the rank of the varieties on this basis the varieties in the early-harvested group were therefore ranked without regard to the dry matter content of the late-harvested group. That is to say, the 12 varieties in the early-harvested group were given rank from 1 to 12, and the variety among the late-harvested group which had the highest dry matter content in that group was given the rank 13. Obviously, many of the later varieties might have had a higher dry matter content on October 15 than did some of the earlier ones on September 25. The ranks on this basis are also given in column 2 of Table 1.

The ranks of the varieties in case of ties have been arrived at by summing the places occupied by the tied varieties and dividing by the number of varieties. To illustrate: In column 5 headed "Date ¼ tasseled," the varieties Square Deal and Northwestern (Will) are tied. There are six varieties leading these two, so that they occupy positions 7 and 8. The average of these positions is 7.5 and this is the rank assigned to each. Similarly, the varieties Falconer, Northwestern, Amenia, Burda, Minnesota No. 23, and Wisconsin No. 25 are tied. They occupy positions 9, 10, 11, 12, 13 and 14. The average of these numbers, 11.5, is the rank assigned to each variety.

It will be noticed that in the case of all the criteria, except "Percentage dry matter," there are a considerable number of ties in rank. In fact some of the varieties are also almost identical as regards dry matter content, and for practical purposes may be considered so. For instance, between Pioneer and Gehu, occupying 4th and 5th places, respectively, there is a difference of only 0.06, the former containing 50.33% and the latter 50.27% dry matter. The highest and lowest of the varieties in point of dry matter among the early group harvested on September 25, which includes the two just mentioned, are, respectively, 41.45 and 53.42%. If all varieties which differ from each other in percentage of dry matter in the ears at harvest by less than 1% (absolute) be regarded as identical, the situation as to variety rank is as shown in the third column of the table under the heading "Percentage dry matter (recalculated)." This simplifies the visual comparison with the other criteria represented by the other columns in the table and does not introduce a significant error.

DISCUSSION

Certain facts in regard to the comparative refinement or fineness of the various criteria are apparent upon superficial examination of the columns in the table. In columns 4, 8, and 14, for example, it is found that many varieties are tied for the same position. In each of these columns as many as eight varieties are tied for one rank. Columns 4 and 8, headed respectively "Date of first tassels" and "Date of first silks," each recognizes only eight "earliness groups" among the 23 varieties compared. Column 14 headed "Stage maturity of ears, September 29" simply shows that these data were taken too late to recognize any differences between the earlier varieties. They do distinguish fairly well between the later ones.

As a final test of the comparative reliability of the various criteria, the method of correlation known as "Spearman's correlation by ranks"[3] has been applied to the data. For this purpose "Percentage dry matter" has been used as the standard of comparison. The dry matter content, if determined from samples properly taken, is an accurate index to comparative maturity. A partial check on its accuracy in this instance is available. The average rank upon the basis of all the criteria, except "Percentage dry matter," and the three discussed in the preceding paragraph, has been determined and appears in column 15. When this ranking is compared with that for "Percentage dry matter (recalculated)," with two exceptions, good agreement is found. Conspicuous lack of agreement is noted in the case of Rustler and to a lesser degree Burda. The comparative ranks of these two varieties under these criteria are, respectively, 13.9 as against 20.0 and 16.9 as against 12.5. Since Rustler has a consistently higher rank as to maturity according to all of the other criteria, there appears to be little doubt that an error has been made in connection with this determination for this variety. In the case of Burda, the rank is not at all consistent under the various criteria, and there is, therefore, no presumption of error in the dry matter determination applied to this variety. It appears, therefore, that the criterion "Percentage dry matter" may be safely used as a standard of comparison in this instance.

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[3] Student. An experimental determination of the probable error of Dr. Spearman's correlation coefficient. Biometrika, 13:263–282. 1922.

In working out the correlation coefficients for the various criteria, those represented by columns 4, 8, and 14, have been omitted for reasons pointed out above. Each of the other columns has been paired in turn with column 2 and the correlation coefficient for each pair calculated.

The following formula has been used

$$P = \frac{\frac{(n^2-1)}{6} - (T_x + T_y) - \Sigma(V_x - V_y)^2}{\sqrt{\left(\frac{n(n^2-1)}{6}\right) - 2_x\Big)\left(\frac{n(n^2-1)}{6} - 2T_y\right)}}$$

since it applies a correction for ties. As a matter of fact the correction appears to be of very little significance as applied to these data, a the correlation coefficients under this formula differ only very slightly from those found when applying the formula which disregards ties, *viz.*, $P = 1 - \frac{6\Sigma(V_x - V_y)^2}{n(n^2-1)}$, such differences being confined to the third and fourth places.

The coefficients for each of the criteria are given below:

Date ¼ tasselled	0.9528 ±0.0142
Date ½ tasselled	0.9248 ±0.0221
Date fully tasselled	0.8850 ±0.0328
Date ¼ silked	0.9200 ±0.0234
Date ½ silked	0.9182 ±0.0239
Date fully silked	0.8911 ±0.0312
Stage maturity of ears, Sept. 15	0.8529 ±0.0410
Stage maturity of ears, Sept. 23	0.8922 ±0.0309
Average of the tassel and ear criteria	0.9600 ±0.0119

All of the correlation coefficients are high. As would be expected, that for the average of the tassel and ear criteria is highest. It suggests a high degree of accuracy in the final classification of the varieties as to earliness and emphasizes what has already been said about the confidence that may be placed in the dry matter determination as a standard by which to measure the relative accuracy of the other criteria.

The coefficient for "Date ¼ tasselled" is conspicuously high. When the other two tasselling dates are compared with the corresponding silking dates ("Date ½ tasselled" with "Date ½ silked" and "Date fully tasselled" with "Date fully silked"), close agreement is found. It seems likely, therefore, that the abnormally large difference in favor of "Date ¼ tasselled" is due largely to chance.

The consistently lower values for the correlation coefficients for the fully tasselled and silked stages, as compared with those for the corresponding earlier stages, might appear at first thought to be a contradiction. As a matter of fact they are entirely in agreement with expectation. It was noted when the data were being taken that some of the varieties, notably the flints and to a lesser degree the semi-dents, tended toward an indeterminate habit of growth. That is to say, plants continued to put forth tillers and it became increasingly difficult as the season advanced to distinguish between tillers and main stalks. Since many of these tillers probably did not produce ears at all and were not therefore reflected in the moisture determinations or other ear criteria, the error introduced is apparent.

As an index to maturity there appears to be little choice between tasselling and silking or between the ¼ and ½ stages, if as indicated above, the abnormally high position of "Date ¼ tasselled" may be ascribed to chance. There is very little difference between the values of the correlation coefficients for "Date ½ tasselled," "Date ¼ silked," and "Date ½ silked."

The observations made upon the ears with reference to their maturity on September 15 and 23 (columns 12 and 13) appear to have been less reliable indices to comparative earliness than tasselling or silking. The correlation coefficients for both of these criteria are lower than any of the four representing the ¼ and ½ tasselling and silking stages. As already pointed out, these observations were made upon every fifth hill, hence upon 10 hills of each row. A considerable range of variation existed, not only in the row but in each hill in many cases.

CONCLUSIONS

Tasselling and silking appear to furnish a reliable basis for comparing varieties or strains of corn as to earliness. Counts should be made after at least one-fourth of the plants have tasselled or silked and probably need not be made later than the date upon which one-half the plants have reached these stages. Either tasselling or silking may be used as the criterion with apparently equal assurance of accuracy. In this investigation plants were regarded as in tassel as soon as anthers had begun to protrude.

Data involving tasselling and silking of course do not give information as to the degree of maturity reached by varieties or strains. By comparing such varieties or strains with a standard whose adaptability to the locality is known, however, eliminations may be made early in the season and more detailed data confined to those varieties or strains which show promise.

UNIFORM STANDS ESSENTIAL IN FIELD PEA VARIETY TESTS[1]

H. W. Hulbert[2]

The fact that large-seeded varieties of field peas had never been high-yielding ones in variety tests at the Idaho Experiment Station led to calibration work in connection with variety testing, a preliminary report of which has appeared in a previous issue of this Journal.[3] The first studies included calibration tests with wheat, oats, and barley as well as peas. However, it was soon found that due to the tillering ability of cereals there was little to be gained by securing equal stands per unit area in small grain variety tests.

METHODS

The field methods used were described in the preliminary report. The actual calibration data were secured by running the seed through the drill at each of various drill set rates. The drill was set on a frame, the seeding tubes disconnected, and 2-quart jars used to catch the seed as it was discharged from the drill.

Previous work at Moscow had proved that the amount of seed in the hopper and the speed of the drill made no difference in the delivery rate.[4] It was also determined that the amount of seed delivered by one side of the drill checked closely with that from the other.

The seed, previously prepared for seeding, was placed in the drill box and the drive wheel turned the same number of revolutions necessary to seed the size of plat used. The calibration delivery was found to correspond almost exactly with actual field delivery.

Stand counts were secured when the young plants were 4 or 5 inches in height by counting the plants in three 1-square-yard areas in each plat.

RESULTS

There is not only less tillering of pea plants but greater extremes in size of seed of different varieties than is found in the small grains. To give an idea of the variation in delivery rate of peas of different sizes, Table 1 was prepared. These data show the number of seeds

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[1] Contribution No. 44 from the Department of Agronomy, Idaho Agricultural Experiment Station, Moscow, Idaho. Received for publication February 23, 1927.

[2] Agronomist.

[3] Bonnett, R. K., and Burkhart, F. L. Rate of seeding—a factor in variety tests. Jour. Amer. Soc. Agron., 15:161–171. 1923.

[4] Hulbert, H. W. Drill calibration and its relation to stand and yield of small grains. Jour. Amer. Soc. Agron., 17:92. 1925.

delivered to the square foot and number of pounds of seed used per acre for each drill set.

The general recommendation for rate of seeding of peas for Northern Idaho is 120 pounds, or 8 pecks, per acre. Seeding each of the three varieties shown in the table at that rate would deliver 12.6, 6.4, and 2.8 seeds to the square foot for the small-, medium-, and large-seeded variety, respectively.

TABLE 1.—*Showing the actual delivery of large-, medium-, and small-seeded varieties of peas, season of 1924.*

	Variety					
Drill set at rate of	Bangalia (3,720 seeds per pound)		Bluebell (2,480 seeds per pound)		Canadian Beauty (1,336 seeds per pound)	
	No. seeds per sq. ft.	No. pounds per acre	No. seeds per sq. ft.	No. pounds per acre	No. seeds per sq. ft.	No. pounds per acre
4 pecks . .	6.3	74.2	3.2	58.7	1.4	46.4
5 pecks . . .	7.6	91.9	4.1	74.7	1.7	57.2
6 pecks .	9.4	110.1	4.8	88.5	2.1	69.8
7 pecks .	10.9	128.8	5.5	101.1	2.4	78.6
8 pecks .	12.6	147.8	6.4	117.3	2.8	91.8
9 pecks	14.0	164.2	7.2	130.6	3.2	103.8
10 pecks . .	15.4	181.1	8.0	145.4	3.5	113.8
11 pecks .	16.9	198.4	8.9	161.4	3.9	127.5
12 pecks .	18.6	217.9	9.7	175.6	4.2	138.1

The ratio of the relationship of the sizes of seed of the varieties previously mentioned is shown in Table 2, with Canadian Beauty as the basis of comparison. It is apparent that the ratio between the number of seeds delivered per square foot is quite constant for the three sizes of seed at all drill sets. For example, at any given rate, 4½ seeds of Bangalia would be delivered to 1 of Canadian Beauty. Apparently, some rate of seeding adjustment must be made so that the yielding ability of the two varieties can be accurately compared.

TABLE 2.—*Showing the ratio of delivery of large seeds (Canadian Beauty) to medium and small seeds, season of 1924.*

	Variety					
Drill set at rate of	Canadian Beauty		Bluebell		Bangalia	
	No. seeds per sq. ft.	No. pounds per acre	No. seeds per sq. ft.	No. pounds per acre	No. seeds per sq. ft.	No. pounds per acre
4 pecks . . .	1	1	2.28	1.25	4.50	1.58
5 pecks . .	1	1	2.41	1.30	4.58	1.60
6 pecks . . .	1	1	2.28	1.26	4.47	1.57
7 pecks . . .	1	1	2.29	1.48	4.54	1.63
8 pecks . . .	1	1	2.28	1.27	4.50	1.61
9 pecks . . .	1	1	2.25	1.25	4.37	1.58
10 pecks . . .	1	1	2.28	1.27	4.40	1.59
11 pecks . . .	1	1	2.30	1.27	4.42	1.57

Actual drill calibration studies were begun in 1922. From these trials, rates of seeding were definitely established and in 1923 all of the pea varieties were seeded at a uniform number of seeds per unit area. In order to secure uniform stands, it was necessary to vary the rate of seeding from 4 to 16 pecks, depending upon the size of seed of the various varieties. The rate of seeding in pounds per acre varied from 65 pounds for Bangalia to 202 pounds for Ne Plus Ultra.

Nine of the varieties in the pea variety test of 1918 were still under trial in 1926. Table 3 shows the effect of drill calibration upon the yield and rank of these varieties.

These data show that the average acre yields of White Canada and Kaiser changed but little during the two four-year periods. This can be accounted for by the fact that drill calibration scarcely changed their rate of seeding. Such varieties have medium- or average-sized seed and the drill set at the recommended rate seeded them at about the proper rate. However, the rank of White Canada and Kaiser was changed materially. This was due to the fact that when seeded correctly some of the other varieties were better able to demonstrate their yielding ability and outyielded them.

Potter, Blue Prussian, and Early Britain previously had been seeded at too low a rate. Even with this disadvantage Early Britain was the high-yielding variety and when seeded at the proper rate its average yield was increased nearly 400 pounds to the acre.

Solo and Blackeyed Marrowfat, two other large-seeded varieties, increased their yields slightly, but apparently did not have the yielding ability to compete with some of the other varieties. Potter, a Marrowfat type, went from fifth to second place when properly seeded.

Bangalia increased both its yield and rank. This is a small-seeded variety and it undoubtedly was seeded too heavily. In fact, to secure

TABLE 3.—*Showing the effect of drill calibration upon the yield and rank of field pea varieties, 1918 to 1926, inclusive.*

Variety	Average yield in pounds per acre, 1918-1921, inclusive	Rank	Average yield in pounds per acre, 1923-1926, inclusive	Rank
Early Britain	1,477	1	1,909	1
Potter	1,360	5	1,733	2
Blue Prussian	1,174	9	1,655	3
Bangalia	1,369	8	1,592	4
Solo	1,296	6	1,527	5
White Canada	1,456	2	1,500	6
Kaiser	1,417	4	1,449	7
Blackeyed Marrowfat	1,005	3	1,406	8
Canadian Beauty	1,197	7	1,169	9

the proper stand, its former rate of seeding was reduced nearly one-half.

PROPER STAND FOR MAXIMUM YIELDS

If drill calibration is to be used successfully in variety tests, the investigator must know the optimum rate of seeding and consequent stand necessary for maximum yields of the various varieties. With this object in mind, Table 4 was prepared from four years' results of drill calibration. The results indicate that the best stand contains from 3 to 3.5 plants per square foot. These data in Table 4 are compiled from all of the varieties grown in the variety test for the year indicated.

TABLE 4.—*Showing the effect of stand upon the yield of field pea varieties, 1923–1926, inclusive.*

Stand, plants per sq. ft.	Total number of varieties considered	Yield in pounds per acre 1923	1924	1925	1926	Mean
3.0 or below	31	2,253	1,345	1,160	1,173	1,509
3.1 to 3.5	24	2,080	1,488	1,478	1,617	1,752
3.6 to 4.0	21	2,059	1,399	1,245	1,598	1,610
4.1 to 4.5	35	1,980	1,554	1,094	1,651	1,624
4.6 or above	20	——	——	983	1,842	1,627
	Total 131				Mean	1,624

Although an average of all varieties grown indicates that 3 to 3½ plants per square foot constitute the proper stand for maximum yields, it is entirely possible that varieties differ in this respect. To check this particular point, seven varieties seeded at varying rates

TABLE 5.—*Showing the relation of stand to yield and number of seeds produced per plant in field peas, season of 1925.*

Drill set at rate of	Pounds of seed per acre	Seeds delivered per sq. ft.	Plants per sq. ft.	Average yield, pounds per acre	Plants per acre	Number seeds produced per acre	Number seeds produced per plant
		White Canada— 2,592 seeds per pound					
4 pecks .	64.25	3.8	2.5	1,720	108,900	4,458,240	40.9[a]
6 pecks .	89.25	5.3	3.4	1,827	148,104	4,735,584	31.9
8 pecks .	115.75	6.9	4.5	1,947	196,020	5,046,624	25.7[b]
10 pecks . .	145.75	8.7	4.9	1,787	213,444	4,631,904	21.7
12 pecks . . .	172.50	10.2	6.0	1,673	261,360	4,336,416	16.6
14 pecks .	200.00	12.0	6.4	1,533	278,784	3,973,336	14.3
		Bluebell 8,257— 1,792 seeds per pound					
6 pecks .	77.50	3.2	2.5	1,913	108,900	3,428,096	31.5[a]
8 pecks . . .	101.75	4.2	3.2	1,960	139,392	3,522,320	25.4
10 pecks . . .	129.25	5.3	4.0	1,973	174,240	3,535,616	20.3[b]
12 pecks . . .	153.25	6.3	4.2	1,913	182,952	3,428,096	18.7
14 pecks . . .	176.75	7.3	5.3	1,727	230,868	3,094,784	13.4
16 pecks . .	209.25	8.6	6.1	1,673	265,716	2,998,016	11.3

[a] Maximum plant efficiency.

[b] Optimum yielding point.

were grown. These selections represented varieties having varying dates of maturity and wide range of seed size. The data shown in Table 5 are representative results obtained with the seven varieties grown on triplicate 1/40 acre plats in 1925.

It will be noticed from the data that the stand which allowed each individual plant to produce the largest number of seed did not produce the greatest total acre yield. In other words, "Maximum plant efficiency," or highest yield per plant, is not desirable if maximum yields of a variety are to be obtained. Therefore, the variety should be seeded at a rate which will allow it to demonstrate its "optimum yielding point." The data in question indicate that the desired stand for this purpose is 4 plants per square foot.

DELIVERY RATE NECESSARY TO SECURE OPTIMUM STANDS

Data over a four-year period indicate that seasonal conditions affect the field germination greatly. In moist seasons higher field germination is secured than in dry seasons. The stand which produces the maximum yields of a variety in one season differs from that giving the best yield in another. However, the same delivery rate will secure maximum yields of a variety in any season, the stand seemingly adapting itself to the seasonal conditions. The calibration data secured at Moscow have shown that a delivery rate of 6 seeds per square foot has given optimum stands in every season.

PRACTICAL VALUE OF CALIBRATION DATA

Presuming that varieties in a variety test are seeded at a definite calibrated rate with the drill set at a definite peck rate, a variety proves itself to be best adapted to a section after having been tested at a definite rate of seeding over a period of years. The variety is then usually recommended and distributed to growers. The rate of seeding best adapted to the variety in question may be included as a part of the recommendation. Other makes of grain drills could also be calibrated and the recommendation broadened to include the proper rate on all of the common makes of drills. Such recommendations will be of greater value to the farmer and will assist in the more rapid establishment of the variety in adapted farming communities.

SUMMARY

Pea varieties should be seeded at a rate which will insure uniform stands per unit area.

The stand producing maximum plant yields does not produce the highest acre yield.

Apparently, 3 to 3½ plants per square foot constitutes the proper stand for conditions in northern Idaho.

The results secured from drill calibration studies will be of value in making rate-of-seeding recommendations.

NOTES

YIELD AND THE NUMBER OF SEMINAL ROOTS IN MAIZE

Field selection to increase the yield of maize is a laborious and expensive method and any discovery simplifying the operation would be of great value. Yield is such a variable character and so difficult of exact determination that maize breeders long have sought some more definite character that might take its place.

The obvious utility of an easily observed morphological character that would serve as an index of yield in maize has inspired a great many investigations, with the result that correlations of a great variety of characters with yield have been measured. Thus far, the search has been disappointing. The coefficients of correlation have always been too small to be of value as an index of yield.

Special interest, therefore, attaches to recent experiments of Smith and Walworth,[1] who report a rather close correlation between yield and the number of seminal roots. The number of seminal roots is easily determined and has the further advantage of being a seedling character, thus making it possible to test large numbers of progenies at any time in the year. Any evidence that high-yielding strains of maize can be detected by counting the number of seminal roots would be very welcome and the experiments of Smith and Walworth should be carefully considered.

They determined the mean number of seminal roots for about 450 individual ears, representing eight varieties. The varietal means ranged from 3.08 to 3.55. From these 450 ears 30 were chosen to determine the relation between the number of seminal roots and early growth and yield. Of the 30 ears selected for this study, 15 were ears showing a high number of seminal roots and 15 were ears with a low number. How these selected ears were distributed among the varieties is not stated, but the mean number of roots in the high group (4.32) exceeds the highest varietal mean and the mean number of roots in the low group (2.43) is below the lowest varietal mean.

The mean yield of the 15 ears with the high number of seminal roots was 29.9 pounds and that of the 15 ears with the low number of roots, 26.3 pounds (given as 26.9 pounds). A consideration of the probable errors of these means indicates a significant difference (3.6 ±0.63). Unless the same varieties are represented equally in the two groups of ears the observed difference in yield hardly justifies the conclusion that yield is associated with the number of seminal roots. Since if more than one variety is involved, it is quite possible that there is simply a difference in the yield of two varieties, one of which happens to have a high and the other a low number of seminal roots. Had ears of the varieties grown by the Indians of the Southwest been included in the comparison, a still greater difference would have been found. These Indian varieties give low yields and the seedlings seldom produce any secondary seminal roots.

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[1] SMITH, L. H., and WALWORTH, E. H. Seminal root development in corn in relation to the vigor of early growth and yield of crop. Jour. Amer. Soc. Agron., 18:1113–1120. 1926.

As a check of the significance of the observed differences in yield, Smith and Walworth calculated the correlation between seminal root number and yield, and a coefficient of $r = 0.50$ is cited as evidence, "That seminal root development may be taken to indicate in some degree the relative inherent productiveness of a seed ear."

This coefficient is remarkably high for any correlation involving yield and might be expected to give a regression that would justify the selection of ears with many seminal roots as a means of increasing the yield. They do not state how the coefficient of $r = 0.50$ was derived, but the method may be a form of the product moment correlation (r), since the latter method gives a coefficient of 0.502 when the groups with high and with low seminal root numbers are combined into a single population. To combine thus into a single population two groups of indivuduals that represent the extremes of the independent variable is to confuse intra- and inter-class correlations and the coefficient is meaningless.

From the data given the product moment correlations of mean number of seminal roots with yield are found to be 0.208 in the group with low number of seminal roots and —0.593 in the group with high number of seminal roots. Neither coefficient is significant, but so far as the evidence goes it indicates that high yield is correlated with *low* number of seminal roots.

The number of seminal roots is an interesting character that deserves further study, but we are forced to conclude that the data presented by Smith and Walworth may not be accepted as furnishing evidence that the number of seminal roots is associated with yield.—G. N. Collins, *Senior Botanist in charge of Biophysical Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.*

SEMINAL ROOTS IN CORN

In connection with the article entitled "Seminal Root Production in Corn in Relation to Vigor of Early Growth and Yield of Crop" published in this Journal (Vol. 18:1113-1120. 1926) questions have been raised concerning two points.

The first question has to do with the method of selecting the seed ears for the comparison in yield of corn high and low in seminal root production. In describing the experiments it is explained that two groups of ears were chosen from a lot of about 450 ears representing eight varieties which themselves exhibited some minor variations with respect to seminal root producing tendencies, but no mention is made as to how the varieties were represented in the selections for the yield test. For those interested, this information is given in the following data which show the distribution of the selected seed ears among the different varieties.

Variety	High number of rootlets	Low number of rootlets
Reid Yellow Dent..........	5 ears	6 ears
Western Plowman..........	3 ears	0 ears
Riley's Favorite...	1 ear	2 ears
Leaming..	1 ear	2 ears
Golden Eagle..............	2 ears	2 ears
Champion White Pearl......	2 ears	1 ear
Silvermine................	1 ear	2 ears

It should be taken into consideration that these are all ordinary varieties grown in Illinois, none of them being considered as extremely diverse with respect to morphological characteristics, habit of growth, or yielding capacity. It appears from the accompanying data that, altho each variety was not represented exactly equally, there was, on the whole, a fairly comparable distribution among the varieties, at least there is no apparent tendency for the opposite selections to group themselves into any certain varieties.

The second question raised in connection with this article is concerned with the use of the correlation coefficient as applied to the data representing the relation between number of seminal roots in seed ears and yield of the same ears (Table 4). It is pointed out that, "To combine thus into a single population two groups of individuals that represent the extremes of the independent variables is to confuse intra- and inter-class correlations and the coefficient is meaningless." (See preceding note.)

The writer agrees with the validity of this objection and is indebted to the critic for calling attention to this misapplication of a statistical method in the treatment of this particular sort of data. The same criticism holds of course to the value of r in Table 3. The value of r, therefore, in this report should be disregarded and conclusions must rest upon the simple numerical averages which in Table 4 should read 29.9 pounds per row for seed of high seminal root tendency and 26.3 pounds for seed of low seminal root tendency.

The writer is still of the opinion, however, that the results of the experiment are sufficiently significant to stimulate further inquiry along this line.—L. H. SMITH, *Charge of Publications, Soil Survey, Illinois Agricultural Experiment Station, Urbana, Ill.*

THE RAPID DETERMINATION OF SOIL MOISTURE BY ALCOHOL

In the February, 1927, issue of this JOURNAL there appeared a brief note by the writer proposing the use of alcohol as the basis for a very rapid means of determining the moisture content of soils and possibly of some other materials. Since the publication of this paper, a large number of letters have been received asking for more detailed information as to the technic, kind of hydrometer used, etc. In view of this large number of inquiries, it has seemed advisable to publish, in advance of the main report, tentative directions for executing a moisture determination, and other essential information concerning the method.

The alcohol method, as far as it has been investigated, seems suitable for the determination of the moisture content of soils very rapidly and quite accurately. The rapidity depends somewhat upon the type of soil, which affects the rate of filtering, the time, however, varies from about three to fifteen minutes. In comparison with the oven method, the results of the alcohol method run a little lower, but not much more than about 1% in the clay soils and much less in the light soils. It seems that the alcohol takes out all the water that exists in the soil in a physical form. Probably the only kind of water that it does not take out is the so-called "chemically bound" water. According to the results obtained, the magnitude of this form of water is probably not very high. If it is, then it would seem that the alcohol probably extracts some of it, probably the more loosely bound.

For the employment of the alcohol method, as has been worked out thus far, the following apparatus is necessary: (1) Alcohol hydrometers made especially for this work. The hydrometers come in a pair. One has a range of from 90 to 100% alcohol and the other from 80 to 90%. They have a very small volume. They are sold by Eimer and Amend and cost about $2.00 each. It is advisable to specify hydrometers made according to the writer's specifications when ordering. (2) An ordinary 25 cc graduated cylinder having an inner diameter of 2 cm. This cylinder is used to hold the liquid while measuring its specific gravity. (3) An ordinary 100 cc graduated cylinder. (4) A 100 cc funnel. (5) A small beaker filled with sand. The sand is used to support the 25 cc cylinder so that it will be easily adjusted to stand absolutely upright when the hydrometer floats. The base of the 25 cc cylinder can be broken off so that the latter can be more easily inserted into the sand. (6) A metal rod about 0.5 cm in diameter. This is used in stirring up soils, in order to break them down or disperse them to the particle state. The alcohol seems to take out the water very rapidly, probably almost instantaneously, but it must penetrate or come in contact with all the soil mass. Therefore, a soil must always be reduced to the particle state.

Before proceeding with the moisture determination the hydrometer must first be calibrated. This is accomplished as follows: The specific gravity of the pure alcohol, which to be used, about 96% by volume, is first ascertained. For purposes of example, let it be assumed that it is 96% alcohol. A volume of 50cc of this alcohol is carefully measured in the 100 cc cylinder, 10 cc of water added to it, and the specific gravity again determined. Suppose that this indicates 82% alcohol in the mixture. The temperature must be recorded and the readings reduced to the same basis, say 20°C. A temperature of 1° makes a difference of about 0.2% alcohol. For temperatures above 20°C the corresponding amount is subtracted from the percentage of alcohol indicated, and for temperatures below 20°C the corresponding amount is added to the percentage of alcohol indicated. When the readings are reduced to the same basis, then the reading of the alcohol which contained the 10 cc of water is subtracted from the reading of the pure alcohol and the difference is divided into the 10 cc of water. This gives the number of cc of water to which each degree on the stem is equivalent. The standard special hydrometer gives 0.714 cc of water for each graduation. To find the number of cc of water in the soil sample taken, the difference in specific gravity of the filtrate and the pure alcohol is multiplied by 0.714.

The general procedure for executing a moisture determination is as follows: Pour 50 cc of the pure alcohol which has been used in calibrating the hydrometers into the 100 cc cylinder. Add to this alcohol 20 grams of the soil whose moisture is to be determined. Disperse the soil by stirring with the rod and using one palm or a small rubber stopper as a stopper. Unless a soil is badly puddled and hardened it slacks or crumbles in alcohol. In case of soils which refuse to slack or crumble, as in the case of some badly puddled and hardened clays, break them up vigorously by means of the rod. If clay sticks on the rod, rub latter vigorously on the walls of the cylinder. Soils filter fastest when only shaken and not when dispersed by rubbing.

The soil, however, should always be reduced to the particle state so the alcohol can come in contact with all the soil mass.

Allow the mixture to stand for a minute in order that the major portion of soil mass may settle. Then pour the supernatent liquid on the filter, allowing the filtrate to drain into the 25 cc cylinder which stands in the sand. Only about 12 to 20 cc of filtrate is required. Place hydrometer in the filtrate and take reading. The latter should be taken on straight line to the surface. Take hydrometer out and determine the temperature of the filtrate. Reduce readings to same temperature basis. Subtract reading of filtrate from reading of pure alcohol and multiply difference by 0.714, or by whatever factor was found in calibrating the hydrometer. The results give the number of cc of water in the sample taken. The percentage of water in the soil is calculated in the usual way.

Care must be taken to rinse vessels with alcohol before using.

The waste alcohol can be recovered so it can be used again by treating it with burned lime.

During the process of filtering it is necessary to cover the funnel to prevent evaporation of the alcohol which would cause an error.

If it is desired to make many moisture determinations, it would be well to have several cylinders and funnels, so that while one sample is clearing up and being filtered, another is being prepared.

Other forms of alcohol could probably be used equally as effectively as ethyl, but probably this is the most practical.

In case of soils containing more than 50% of moisture, such as mucks and peats, only about 10 grams or less of soil should be used to 50 cc of alcohol.

By following the above directions the method seems to work remarkably well and accurately. A technic is being worked out to use this method under field conditions as well.—GEORGE J. BOUYOUCOS, *Research Professor in Soils, Michigan State College, East Lansing, Mich.*

AGRONOMIC AFFAIRS

SPECIAL COMMITTEES

PRESIDENT BURLISON has appointed the following special committees to serve for the purposes indicated in each case:

JOINT COMMITTEE ON TERMINOLOGY FOR SEED OF IMPROVED VARIETIES OF GRAIN

(Members representing the American Society of Agronomy)

G. H. Cutler, *Chairman*   Clyde McKee   O. W. Dynes
F. P. Bussell   R. A. Moore

(Members representing the International Crop Association)
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COMMITTEE ON CHILEAN NITRATE AWARD

M. F. Miller, *Chairman* A. T. Wiancko F. J. Alway
B. L. Hartwell Oswald Schreiner T. L. Lyon
J. R. Fain F. D. Gardner C. B. Williams

NEWS ITEMS

Richard Bradfield, Associate Professor of Soils at the University of Missouri, has been appointed to a John Simon Guggenheim fellowship in order to make an investigation of the principles involved in the purification of colloidal materials by electrodialysis and will work chiefly in the laboratory of Herbert Freundlich at the Kaiser Wilhelm Institute, Berlin, Germany.

John G. Willier, who has been Assistant Agronomist in corn investigations in the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, resigned his position on March 1, 1927.

The Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, has recently completed the erection of a most up-to-date greenhouse at the Arlington Experiment Farm for use in corn investigations.

Orman E. Sweet has resigned and Robert S. Horne has been appointed as his successor as Investigator in Agronomy at the Massachusetts Agricultural Experiment Station, at Amherst, Mass.

R. W. Webb, Associate Pathologist in the investigation of cereal virus diseases in the Office of Cereal Crops and Diseases of the Bureau of Plant Industry, U. S. Department of Agriculture, was transferred on March 11 to the Cotton Division of the Bureau of Agricultural Economics of the Department, where he will have charge of studies of the physical properties of cotton fibre in relation to cotton standards.

B. B. Bayles, formerly Junior Agronomist in charge of the cereal breeding work at the Sherman County Branch Station at Moro, Ore., has been transferred to Moccasin, Mont., to succeed R. W. May as Assistant Agronomist in charge of cereal experiments at the Judith Basin Substation.

T. B. Hutcheson, Agronomist of the Virginia Agricultural Experiment Station, was elected Chairman of the Agronomy Section of the Association of Southern Agricultural Workers at the annual meeting of the Association held at Atlanta, Ga., in February.

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SYMPOSIUM ON "POTASH"

Leader: C. A. Mooers, Director, Tennessee Agricultural Experiment Station.

1. "Geography of Potash Needs of Soil Provinces of the Eastern Half of the United States." J. N. Harper, Agricultural and Scientific Bureau, N. V. Potash Export My.
2. "Relative Crop Response to Potash." Burt L. Hartwell, Rhode Island Agricultural Experiment Station.
3. "Potash in Relation to Plant Diseases." (By title only.) G. N. Hoffer, Indiana Agricultural Experiment Station.
4. "The Influence of Liming on the Availability of Soil Potash." W. H. MacIntire, W. M. Shaw, and K. B. Sanders, Tennessee Agricultural Experiment Station.
5. "Potash in Relation to Quality of Crop." Geo. L. Schuster, Delaware Agricultural Experiment Station.

1. GEOGRAPHY OF POTASH NEEDS OF SOIL PROVINCES OF THE EASTERN HALF OF THE UNITED STATES[1]

J. N. HARPER[2]

Most of the soils of the eastern half of the United States need potash for profitable crop production. This need varies with different soil types and is influenced by their geological origin, manner of formation, texture, climatic conditions, topography, and colloidal and lime content.

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[1] Paper read as a part of the symposium on "Potash" at the meeting of the Society held in Washington, D. C., November 19, 1926.

[2] Joint Director, Agricultural and Scientific Bureau, N. V. Potash Export My., New York, N. Y.

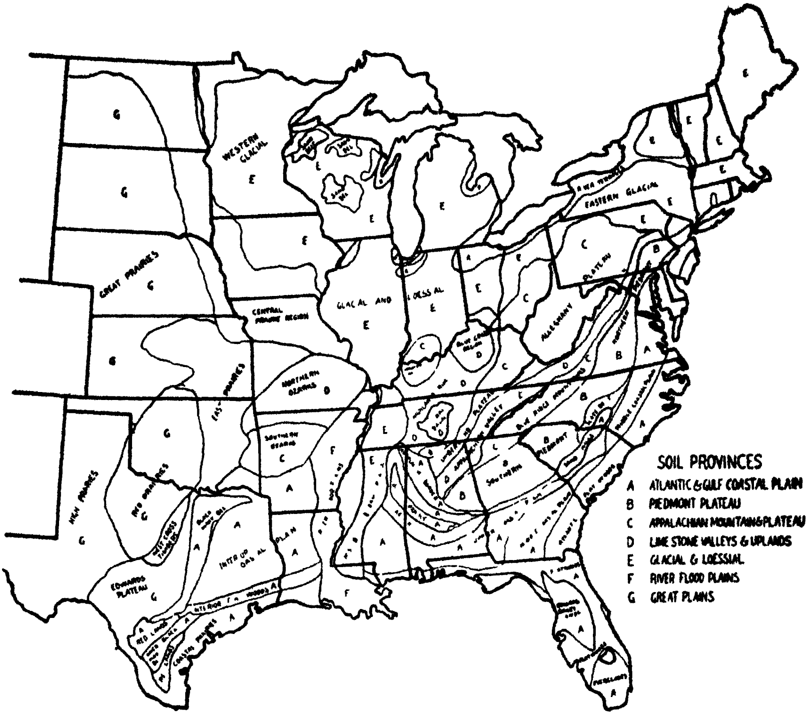

FIG 1

Similarity of origin and texture of certain soil types has led to the designation of soil provinces The eastern half of the United States is divided into seven of these provinces; *viz.*, the Glacial and Loessial, the Limestone Valleys and Uplands, the Appalachian Mountains and Plateau, the Piedmont Plateau, the Atlantic and Gulf Coastal Plain, the River Flood Plains, and the Great Plains. The passing of hundreds of years will bring little or no change in the well-defined characteristics of these soil provinces. Soils of the Coastal Plain province will always remain sandy loams and the soils of the Limestone Valleys and Uplands will always remain silty loams.

Although there is a variation in the potash needs of the different soil provinces, there is an even wider variation in the potash needs of the soil types within these provinces. For this reason the relative potash requirement of the provinces cannot be designated on a map, except in a general way. The accompanying map shows the provinces and the regions within each province.

The provinces and the regions in the order of their potash needs in the light of present knowledge are listed below. For example, the Atlantic and Gulf Coastal Plain is the province requiring the most potash and the sand hills is the region within that province that has the greatest need of potash.

A. Atlantic and Gulf Coastal Plain Province
    a. Sand hills
    b. Atlantic flat woods
    c. Middle coastal plain
    d. Rolling sandy lands
    e. Upper coastal plain
    f. Appalachian border, interior coastal plain and red lands
    g. Clay hills, interior flat woods and coastal prairie
    h. Black prairie and black waxy belt
B. Piedmont Plateau Province
    a. Southern Piedmont
    b Sandstone and shale belt
    c. Slate belt
    d Northern Piedmont
C. Appalachian Mountains and Plateau Province
    a. Cumberland plateau
    b. Southern Ozarks
    c. Allegheny plateau
    d. Blue Ridge Mountains
    e. Western coal fields
D. Limestone Valleys and Uplands Province
    a. Highland rim
    b. Northern Ozarks
    c. Appalachian Valley
    d. Central basin of Tennessee and bluegrass region of Kentucky
E. Glacial and Loessial Province
    a. Mississippi bluff and silt loam uplands
    b. Glacial lakes and river terraces
    c. Eastern glacial
    d. Northern loessial and glacial
F. River Flood Plains Province
    a. Ridge lands
    b. Second bottom lands
    c. First bottom lands
G. The Great Plains Province

This province is still virgin territory and since its natural store of potash has not been drawn on there is little variation in the potash requirements of crops over the entire province. The soil regions of the province are therefore not included in the list.

In the light of experiment station results, observation of farm practices, the results of chemical analyses, and reports from soil

TABLE 1.—*Correlation of the principal soil types of the different provinces as to their potash needs.*

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
			Atlantic and Gulf Coastal Plains		
Leon	Ruston	Greenville	Susquehanna	Houston	Trinity clay
St. Lucie	Gainesville	Blakely	Oktibbeha	Crockett	Victoria
Blanton	Parkwood	Orangeburg	Lauderdale	Duval	
Norfolk	Elkton	Sassafras			
Plummer	Coxville				
Tifton					
Marlboro					
Portsmouth					
Muck					
			Piedmont Plateau		
	Durham	Granville	Wadesboro	Penn	
	Cecil sand	Appling	Chester	Cecil clay	
	Alamance	Georgeville	Madison	Mecklinburg	
	Iredel	Cecil sandy loam	Davidson	Louisa	
			Appalachian Mountains and Plateau		
		Dekalb	Upshaw	Porters	
		Conasauga	Hanceville	Westmoreland	
		Ashe	Meigs	Talledega	
			Tilset		
			Limestone Valleys and Uplands		
		Clarksville	Colbert	Baxter	Hagerstown
		Guthrie	Lebannon	Decatur	
			Glacial and Loessial		
		Coloma sandy loam	Dunkirk sand	Clermont silt loam	Crosby silt loam
		Miami sandy loam	Memphis	Miami silt loam	Brookton silt loam
		Volusia	Glaucester sandy loam	Carrington sandy loam	Miami clay
		Clyde sandy loam	Fargo fine sandy loam	Grenada	Knox
		Merrimac sand			Marshall silt loam
					Wooster silt loam
			River Flood Plains		
			Yahola fine sandy loam	Portland fine sandy loam	Miller clay
			Brewer fine sandy loam	Muscogee silt loam	Portland clay
			Muscogee fine sandy loam	Crowley silt loam	Sarpy
			Lintonia fine sandy loam	Waverly silt loam	Sharkey clay
					Vicksburg clay

specialists and soil surveys, I have attempted to correlate the principal soil types of the provinces by assembling them into six groups according to their potash needs as shown in Table 1. The types in Group 1 require the most potash and those in Group 6 require the least potash.

Group 1, with the largest potash requirements, includes the white sandy soils, the grey sandy soils, the dark sandy loams, and muck soils, of the Atlantic and Gulf Coastal Plain. Potash is needed for all crops in large amounts, truck crops demanding the most.

Group 2, with the second largest potash requirements, includes the grey sandy loams of the Upper and Middle Coastal Plain and the grey sandy soils of the Piedmont Plateau. All crops require potash in relatively large amounts.

Group 3 embraces the grey to red sandy loams with red sub-soils of the Atlantic and Gulf Coastal Plain, the red to brown sandy loams with red to yellow sub-soils of the Piedmont Region, the grey to brown silt loams with yellow sub-soils of the Appalachian Mountain Sand Plateau, the grey silt loams with yellow sub-soils of the Limestone Province, the muck soils of the Glacial Lakes and River Terraces, and the coarse sandy loams of the Glacial and Loessial Province. General crops require potash in medium amounts, truck crops in large amounts.

Group 4 includes the grey to dark brown sandy loams of the Atlantic and Gulf Coastal Plain, the grey to red brown loams of the Piedmont plateau, the grey to brown silt loams of the Appalachian Mountains and Plateau, the grey silt loams of the Limestone Province the dark sandy loams of the Glacial and Loessial Province, and the grey to brown fine sandy loams of the River Flood Plains. These soils require large amounts of potash for those crops that readily respond to potash and have high acre values.

Group 5 is composed of the dark grey calcareous loams of the Atlantic and Gulf Coastal Plain, the red to dark brown clay loams of the Piedmont Plateau, the red to brown silty loams with red sub-soils of the Appalachian Mountains and Plateau, the grey silty loams with red clay sub-soils of the Limestone Province, the grey to brown silty loams of the Glacial and Loessial Province, and the grey to brown fine sandy loams of the River Flood Plains. These soils require medium amounts of potash for those crops that give relatively large response to potash and have high acre values. The length of time the land has been in cultivation and the previous methods of cropping have a great deal to do with the potash requirements of the soils in this group. All other groups of soils, of course, are influenced in the same way.

Group 6 includes the dark calcareous clay of the Atlantic and Gulf Coastal Plain, the red to brown silty loams with dark brown sub-soils of the Limestone Province, the brown silty and clay loams of the Glacial and Loessial Province, and the dark grey to brown silty loams of the River Flood Plains. Very little potash is needed except for those crops with high acre values grown on land that has long been in cultivation.

Abundant evidence shows that, while two soil types may contain the same total amount of potash, they may not necessarily show equal response in crop yields, because the factors that control availability may be more favorable in one than in the other. Long continued fertilizer experiments show that soils in cultivation lose their available potash and regardless of their large native store sooner or later respond to applications of soluble forms.

Soils having a small store of available potash respond to applications of soluble forms after the first few years of cultivation, notably the Norfolk, Marlboro, and Tifton soils of the Coastal Plain. But Greenville and Orangeburg soils of the same province, containing a larger supply of available potash, can be cropped appreciably longer before a marked deficiency develops.

A careful study of experiment station data appears to indicate that the age of the soil is correlated with potash needs. Old granitic soils of the Piedmont Plateau need larger applications than the younger granitic soils of the Glacial and Loessial Province. Rainfall undoubtedly has its influence as is shown by the fact that in the southeast where there is frequent rainfall there is greater need for potash than on the same soil types in the southwest where there is less rainfall.

Population increases will necessitate bigger crop yields and this demand will be met largely through the more liberal use of fertilizers. The present cropping systems are rapidly depleting the store of available potash. Their annual draft in the eastern half of the United States amounts to about 3,000,000 tons of potash. Of this amount approximately 800,000 tons is returned through crop residues and manures, and only about 200,000 tons is returned in commercial fertilizers. Using simple arithmetic this leaves the soils poorer each year by 2,000,000 tons of available potash, not considering the losses through leaching and surface washing.

2. RELATIVE CROP RESPONSE TO POTASH[1]

BURT L. HARTWELL[2]

The subject which has been assigned to me has to do with the relative capacity of different crop plants to obtain their potash needs *in a given set of circumstances.* The crop which is least able to secure its potash needs will of course respond most to an application of potash, and *vice versa.*

Because we are to compare crops, instead of the influence of situations, such as positions in rotations, it follows that the different crop plants must be compared under the same conditions if their relative response is to be learned.

The response of crops under different conditions is another question, requiring for its answer a comparison of conditions rather than of crop plants. This distinction should be recognized clearly.

Usually, in practice, different crops are not grown under the same soil conditions and frequently not at the same time of year, even when grown in an identical location. Therefore, data concerning the relative response of different crops are quite meager.

Attempts should be made to secure more knowledge on this subject for under identical conditions responses differ so widely with the different crops that these characteristics are fundamental to the selection of a fertilizer grade for a crop, subject to such modifications as may be made when it is known, for example, what is the influence on that crop of position in rotation or of different climatic conditions. In order, therefore, to ascertain the relative response of crops to any one fertilizer ingredient it is necessary that all conditions be as nearly optimum as they can be made, except that there should also be an area with sub-optimal potash for comparison. Organic matter, soil reaction, and the supply of nutrients can be controlled, but the influence of the weather on the relative response can only be estimated. However, unless the weather is quite unsuited to some of the crops under comparison, considerable confidence may be had in the results.

The most direct measure of the degree of suitability of the attempted optimal conditions is the yield of the crop. Therefore, in considering the relative response of crop plants there should be stated not only the varieties but especially the maximal yields to which reference is made. Obviously the response, for example, of a small crop of corn should not be considered as "relative" to the response of a large crop of potatoes, at least unless such extreme yield differences are clearly recognized.

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[1] Paper read as a part of the symposium on "Potash" at the meeting of the Society held in Washington, D. C., November 19, 1926. Contribution 340 from the Rhode Island Agricultural Experiment Station.

[2] Director and Agronomist, Agricultural Experiment Station, Kingston, R. I.

In 1921, the author (1),[3] for a special purpose, grouped tentatively certain crops as low, medium, and high in respect to their relative response to fertilizer ingredients, but with the distinct reservation that there was "scarcely any experimental data in existence suitable for the purpose under discussion."

Since that time other results have become available at the Rhode Island Station concerning the relative response of crops to each of the three fertilizer ingredients, but on this occasion attention will be confined mainly to the subject of potash.

Results (2) of field comparisons of spring cereals were published in 1922, and in 1922 and 1923 one of these cereals (oats) was grown in comparison with other crops including potatoes (3). In 1926 potatoes were compared with still other crops.

The results of these comparisons during five years have made possible the arrangement in Table 1 of the crops in accordance with their increasing response to potash in relation to oats, to potatoes, and to one another.

TABLE 1.—*Certain crops arranged relatively in the order of their increasing response to potash.*

Year of comparison	Crop, variety, and yield unit	Yields per acre with optimal fertilizer
1921–23	Oats, hay, dry matter, tons	1.88
1921–22	Rye, spring, hay, dry matter, ton	0.84
1921–22	Wheat, spring, Marquis, hay, dry matter, ton	0.79
1921–22	Millet, Japanese, hay, dry matter, tons	4.45
1922–23	Carrots, Half Long, roots, bushels	831.0
1921–22	Barley, Swanshals, hay, dry matter, tons	1.16
1926	Rutabagas, Macomber, roots, tons	18.3
1926	Parsnips, Hollow Crown, roots, tons	20.0
1922, 1923, and 1926	Potatoes, Russet Rural, bushels	283.0
1922–23	Cabbage, Ball Head, heads, tons	17.6
1926	Tomatoes, Livingston's Globe, total fruit, tons	24.1
1922–23	Mangels, Giant Half Sugar, roots, tons	35.1
1921–22	Buckwheat, Japanese, hay, dry matter, tons	4.02
1922–23	Corn, R. I. White Cap, ears, bushels	64.0
1922–23	Onions, Yellow Globe, bushels	471.0

[3] Reference by number is to "Literature Cited," p. 482.

The yield on an area with insufficient potash in comparison with the yield with optimal fertilizer ranged from 16% for onions to 88% for oats. By dividing this range into three equal parts the crops are grouped as follows: Low potash-response crops, oats, rye, wheat, millet, carrots; medium potash-response crops, barley, rutabagas, parsnips, potatoes, cabbage; high potash-response crops, tomatoes, mangels, buckwheat, corn, onions.

It should be kept in mind that the degree of response depends to a considerable extent upon the size of the crops produced with optimal fertilizer. For this reason the table contains such yields which may be compared with those considered as normal in other situations. The yields of certain crops in the table will be recognized as rather low and others as larger than usual.

Fortunately, the rainfall was fairly well distributed during the experimental seasons and, therefore, it is probable that the lack of potash was at least the main factor curtailing growth on the sub-optimal-potash areas.

A committee (4) of New England agronomists has suggested that in fertilizers the proportions of the fertilizer ingredients be represented by certain given numbers the sum of which shall be about 20 in each fertilizer, and that such an expression be known as a fertilizer *ratio*, not *grade* or analysis. Standard ratios rather than grades might be adopted. A number of grades of a given ratio may exist because of differences in concentration, for example, a 5–8–6 ratio might be represented not only by a 5–8–6 grade but also by a 10–16–12 grade.

The numbers recommended for potash were: very low, 2; low, 4; medium, 6; high, 8; very high, 10.

In a medium-potash situation the ratio numbers for potash would be 4, 6, or 8, depending on whether the crop under consideration belongs to the low, medium, or high potash-response group. If the soil were known to be markedly deficient in potash, the three appropriate numbers might be 6, 8, or 10, respectively; or, if quite well supplied with potash, the numbers might be 2, 4, or 6.

When considering a fertilizer ratio for a given crop, the relative amount of the three different ingredients is the main consideration and not the relation of potash to the sum of the three ingredients (about 20). If, for example, there is a crop that exhibits a high response for each of the three ingredients the relation would be represented by 6–12–8, using the numbers suggested by the committee for "high"; but since the sum of these numbers is not about 20, the ratio would be expressed as 5–10–6 by adopting the numbers proposed for "medium", since the sum of these numbers is the nearest to 20, and yet they represent practically the desired proportion of the three ingredients.

The results of chemical studies of the soils and crops will be discussed at another time.

If the relative responses as given in the table differ from the ideas of some of us in connection with fertilizer grades, compatability may be established by a consideration of yields or of the different conditions under which the crops in question are customarily grown. For example, if there is surprise that corn has a higher relative response to potash than has potatoes, the question should arise as to what extent the fertilizer grades are determined by considering which of the two crops usually has the most advantage from sod and manure.

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4. ————, ABBOTT, J. B., JONES, J. P., and MORGAN, M. F. Plant nutrition in relation to a general soil fertility program. Jour. Amer. Soc. Agron. 17:68–72. 1925.

3. POTASH IN RELATION TO PLANT DISEASES

G. N. HOFFER

(This paper was read as a part of the symposium on "Potash" at the meeting of the Society held in Washington, D. C., November 19, 1926; but was subsequently withdrawn by the author for addition and amendment and possible separate publication.—EDITOR.)

4. THE INFLUENCE OF LIMING ON THE AVAILABILITY OF SOIL POTASH[1]

W. H. MacIntire, W. M. Shaw, and K. B. Sanders[2]

INTRODUCTORY

It has been assumed and taught that the addition of lime to soils results in the liberation of potash through chemical reaction. Numerous citations to this effect could be given. Quite a number of workers have reported that after a soil had been suspended in aqueous solution of different salts of calcium there was found in solution a greater amount of potassium than could be extracted from the soil by water alone. In such observations, however, the soil had not been limed previously, nor was it exposed to a solution which contained both neutral salts and hydroxide, or carbonate, of calcium (20).[3] This condition was in effect, however, in certain lysimeter studies (13) at the Tennessee Station.

If some distinction had been drawn between the "fixed" calcium and that present as soluble neutral salts, it might have been taught, with some logic, that liming causes increased quantities of calcium salts to occur in the soil system and that such increases bring about an enhancement in soluble potash. Even this assumption would have ignored the possible influence of a store of less soluble calcium compounds. But such distinction was not drawn, so that in time it was generally assumed and taught that potash liberation was induced by lime, *per se*. This viewpoint was derived from laboratory studies and it disregards the fact that often all, or at least the larger part, of finely divided, well mixed, economic lime additions are quickly "fixed," or absorbed, in non-carbonate form by the soil. Furthermore, a large amount of hydroxides of calcium or magnesium may be "fixed" by the non-potassic "acidoids," such as silica (10, 14) or other solid acid materials of the soil, exclusive of any question of forcing out potassium, or other bases.

It is recognized, of course, that soil potassium may be brought into soluble form if the soil be subjected to extended contact with solutions of $Ca(OH)_2$. That is, a heavy concentration of hydroxyl ions will bring about hydrolysis of the soil's potassic complexes. It has been shown (9) that lime additions—so excessive (100 tons) as to impose such a condition for a long period under outdoor exposure—will result in potash liberation. In this particular case the CaO had not entirely reverted to the carbonate at the end of three years (8) and the leachings showed that the soil had been bathed with $Ca(OH)_2$-impregnated rain water during that period. Such an excessive admixture approaches laboratory manipulation and the determined liberation is solely of academic interest, in so far as practical liming is concerned. Under most conditions, 2 tons of CaO per acre would be considered a maximum application. It has been shown that such an application, or its equivalent of hydrated lime or finely divided carbonate, will be in either the "fixed" or the carbonated form within a few days (8) after its thorough incorporation with an acid loam. Therefore, since the present discussion is intended as a possible contribution to practice, no treatments in excess of a 2,000-pound CaO-equivalent will be considered.

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[1] Paper read as a part of the symposium on "Potash" at the meeting of the Society held in Washington, D. C., November 19, 1926.

[2] Soil Chemist, Associate Soil Chemist, and Assistant Soil Chemist, respectively, Tennessee Agricultural Experiment Station, Knoxville, Tenn.

[3] Reference by number is to "Literature Cited," p. 504.

NATURE OF SOIL POTASH

The potash of the soil may be considered as occurring in three forms, or degrees, of fixation. One form may be directly dissolved by water, by weak organic acids, by dilute mineral acids, or may be brought into solution through the interchange effected by neutral salts. A second form will yield to the solvent action of strong and concentrated mineral acids, whereas the third is disrupted completely into soluble combinations only by severe alkali fusions or hydrofluoric volatilization. The first may be considered as being held more by the force of those surface phenomena which are characteristic of soil particles of the greatest subdivision. The second may include the more soluble native minerals, as well as fractions of those less soluble; whereas the third, or residual, form may be considered as being the most complex and insoluble silicate minerals. That fraction of the soil's potash which has reached the state represented by the first form is that which may be considered as (a) the cumulative effect of those replacement or interchange reactions which are inherent to the dynamic soil system, (b) as derived from decomposition of plant residues, or (c) from fertilizer additions.

PREVIOUS RELATED OBSERVATIONS

Tressler (18), MacIntire (9, 13), Plummer (16), and Haley (4) have given bibliographies of the lime-potash subject. To these will be added only certain earlier uncited results and subsequent reports.

Storer (17), and others subsequently, pointed out that calcium sulfate will effect the liberation of soil potash. This effect was also observed in studies on the Pennsylvania Station field plats where $CaSO_4$ was engendered by additions of ammonium sulfate (7). MacIntire, Shaw, and Young (13) showed, however, that $CaSO_4$ did not so function where either CaO or MgO was also added.

When the repeatedly limed plats of the Pennsylvania Station were 30 years old, Brown and MacIntire (2) made aqueous 1–5 extractions on moist samples each week for 17 consecutive weeks. These extractions gave a potash recovery less than that obtained from the untreated soil. This demonstrated that the residual potash had either decreased in solubility or diminished in quantity. The K_2O content of the wheat crop (5) from the limed soil was also less than that of the wheat from the unlimed plats.

Frear and Erb (3) showed that a large part of the K_2O, progressively added to the unlimed loam of the Pennsylvania Station, was still present after 36 years. From results obtained by several methods of extraction they concluded that, "Taken as a whole, the conclusion is warranted that much of the potash applied as fertilizer remains in the surface soil in a state highly available to plants, that most of it remains there in a condition of lower availability, and that the losses by drainage have probably not been great." The first part of the present work was planned independently of the outline followed by Frear and Erb, nevertheless, it is a close parallel to their efforts.

STUDIES WITH FIELD-PLAT SOILS

METHODS

Three Tennessee soils which have been studied by plat culture for respective periods of 7, 17, and 21 years were used for determinations of the influence of liming upon present potash availability. The three soils were a fairly fertile reddish-brown loam from Murfreesboro, a gray silt loam from Jackson, and a fertile brown (Cumberland) loam from Knoxville. The analyses of and yields from these soils have recently been reported by Mooers (15).

One to five aqueous digestions, with agitation at 30-minute intervals for 8 hours and overnight standing, were made with both distilled and carbonated distilled water. The same digestion was carried out with N/5 HCl, ratio of 1:10. The K_2O recoveries by leachings to equilibrium with N/20 HCl and with N/1 NH_4Cl were also determined. One to 10 digestions with HCl (1.115) for 10 hours were likewise made, primarily as a control upon variability attributable to sampling and also to gauge the relationship between the readily released potash and that which may be considered as an ultimately available supply. One-half millimeter sievings were used in all cases. The data for the three soils are given in Tables 1, 2, and 3.

DISCUSSION

From the data of Table 1 it appears that, when applied alone, lime has resulted in a diminution in potash availability, as measured

TABLE 1.—*Influence of liming upon availability of native and added potash of a cropped soil after 7 years as measured by various solvents, Murfeesboro.*[a]

Plat	Treatment in pounds per acre during 7 years				Pounds of K_2O per 2,000,000 pounds of soil after 7 years of cropping					
					1 to 5 aqueous digestions		HCl			NH_4Cl
	Limestone	Potash	P_2O_5	Nitrogen	Distilled	Carbonated	1.115 1 to 10 digestions	N/5 1 to 10 digestions	N/20 Leaching	N/1 Leaching
9	None	None	None	None	31	66	5,700	300	320	320
9	4,000	None	None	None	24	50	6,000	280	360	220
10	None	None	384	60	34	67	6,280	280	260	340
10	4,000	None	384	60	26	58	6,180	320	320	380
11	None	150	384	60	41	80	6,160	440	480	360
11	4,000	150	384	60	43	82	6,460	440	460	360

[a] Rotation soybeans, wheat, clover and grass, and corn and cotton.

TABLE 2.—*Influence of liming upon the availability of native and added potash of a cropped soil after 17 years as measured by various solvents, Jackson.*[a]

Plat	Treatment in pounds per acre during 17 years			Pounds of K_2O per 2,000,000 pounds of soil after 17 years of cropping					
				1 to 5 aqueous digestions		HCl			NH_4Cl
	Limestone	Potash	P_2O_5	Distilled	Carbonated	1.115 1 to 10 digestions	N/5 1 to 10 digestions	N/20 Leaching	N/1 Leaching
10	None	None	None	45.6	61.2	3,820	240	260	160
10	4,000	None	None	40.8	74.4	3,280	280	240	240
11	None	None	544	33.6	42.0	3,780	160	120	100
11	4,000	None	544	22.8	39.6	3,220	180	160	140
12	None	425	544	77.5	80.4	4,160	300	320	280
12	4,000	425	544	52.8	69.6	3,680	260	260	260

[a] Rotation of cowpeas and wheat.

by aqueous extractions of the Murfreesboro soil after 7 years of cropping. The same result was also noted where acid phosphate was applied with and without lime. To some extent this may be due to a greater removal of potash by the larger growth which was obtained where lime was added. The calcium sulfate carried by the acid phosphate most probably functioned differently in the limed and unlimed plats (13). However, this factor can not be considered here, except as one result of the use of the acid phosphate.

The amounts extracted by all solvents were practically the same for respective comparisons where *potash* had been *applied*, with and without lime. The potash recoveries from the potash plats were, however, consistently higher than those secured from the four plats to which no potash had been applied. The comparatively uniform values obtained by the extractions with the two weaker acids and NH_4Cl justify the grouping of these data to obtain grand averages. The average of all 10 dilute-solvent results from the two unlimed, no-potash plats amounts to 202 pounds, whereas the corresponding average from the limed plats is 204 pounds. The weak-acid and the NH_4Cl extractions show potash concentrations of somewhat comparable values for the no-potash plats, although the variations between limed and unlimed soil were not consistent.

The average of the nine weaker-solvent extractions from the unlimed areas is 344 pounds, while that from the limed areas is 349 pounds. The average of the six aqueous extractions from the unlimed sectors is 53.1 pounds, while that from the limed areas is only 47.1 pounds. But the average of the three concentrated-acid determinations for these same areas is 6,047 pounds and 6,213 pounds, respectively. Accordingly, when the averages of the three concentrated-acid digestions of unlimed areas are compared to the average of six aqueous extractions and to the nine dilute-acid and NH_4Cl extractions from the same areas, 0.88% of the total acid-soluble potash was removed by the aqueous extractions and 5.69% by the three stronger solvents. A corresponding calculation for the limed areas gives 0.76% and 5.61%. However, the variation of 580 pounds between the concentrated-acid extractions of the two no-lime, no-potash plats militates against the drawing of fine conclusions. Thus, with this particular soil, it is only the water-soluble results which show consistent differences.

In corresponding attempts to show the effect of potash additions by the totals derived from fusions, or by concentrated-acid digestions, Frear and Erb (3) and the senior author (6), encountered the same difficulty, whereas the correlated aqueous extractions in both of the foregoing studies resulted in findings similar to those now reported.

In the case of the Jackson soil the results of Table 2 show relations similar to those obtained from the Murfreesboro soil for the water-soluble potash in three of the four comparisons; but in this case liming also produced a depressive effect where potash was added. As before, the soil variations indicated by discrepancies between the maximum and minimum concentrated-acid digestions and the lack of consistency in the results by the two weaker-acid and NH_4Cl solvents are against positive conclusions. The tendency, however, is again toward evidence of depressed potash solubility where lime was added.

The average of the six aqueous extractions of the unlimed areas of this soil is 56.7 pounds as against 50 pounds from the limed sectors; whereas corresponding averages from the nine dilute-acid and NH_4Cl extractions are 217 pounds and 224 pounds. However, the averages from the concentrated-acid extractions for the unlimed areas were 3,920 pounds against only 3,393 pounds for the limed areas. Therefore, the six water-soluble and nine dilute-acid NH_4Cl extractions represent, respectively, 1.44% and 5.54% of the maximum, or concentrated acid, recovery for the unlimed soil and 1.47% and 6.60% for the limed soil.

The Knoxville (Cumberland) loam, Table 3, affords four comparisons, including one between two plats which had been manured with a total of 84 tons of manure, with and without lime, over the 21-year period. All of the results with the five weaker solvents are uniform for the untreated soil and that which received lime alone. The five analytical procedures failed to show any consistently marked differences between the limed and unlimed sections to which potash had been applied. The same is true for the potash-phosphate series. In both of these series, however, the distilled water extracted less potash from the limed area than from that unlimed. The same was true also for the manurial series. The heavy additions of potash through manure failed to show comparatively in the aqueous extractions. This may be due to the fact that considerable lime had been progressively supplied along with the potash of the manure. But the strong acid digestion likewise failed to register increased supplies of potash. Some indication of increased potash stores was given, however, by the other three solvents.

The eight water-extractions from the four unlimed plats give an average of 39.3 pounds against 35.6 pounds for the limed areas. The 12 dilute-acid and NH_4Cl extractions give corresponding values

TABLE 3.—*Influence of liming upon the availability of native and added potash of a cropped loam soil after 21 years as measured by various solvents, Knoxville.*[a]

Plat	Treatment during 21 years				Pounds of K_2O per 2,000,000 pounds of soil after 21 years of cropping					
	Burnt lime	Potash	P_2O_5	Manure	1 to 5 aqueous digestions		HCl		NH_4Cl	
	Pounds	*Pounds*	*Pounds*	*Tons*	Distilled	Carbonated	1.115 1 to 10 digestions	N/5 1 to 10 digestions	N/20 Leaching	N/1 Leaching
14	None	None	None	None	21.6	30.0	3,960	120	120	100
14	3,800[b]	None	None	None	21.6	27.6	4,440	120	140	120
J8	None	525	None	None	39.3	50.4	4,400	100	200	340
J8	3,800[b]	525	None	None	33.6	67.2	4,400	100	260	320
G5	None	525	504	None	39.3	32.4	4,400	120	120	140
G5	3,800[b]	525	504	None	17.5	32.4	4,280	100	100	100
G6	None	1,138[c]	168[d]	84	41.6	60.0	4,400	260	260	320
G6	3,800[b]	1,138[c]	168[d]	84	36.0	49.2	3,860	240	260	240

[a] Rotation, cowpeas and wheat.

[b] 1,800 pounds initially and 2,000 pounds after 12 years.

[c] 1,008 pounds, assuming 0.6% K_2O in manure, plus 130 pounds from KCl.

[d] Not including that carried by the manure.

of 183 pounds and 175 pounds. The greater uniformity of the soil used in this field experiment is shown by the average of the four concentrated-acid extractions, 4,290 pounds, for the unlimed plats as against a similar average of 4,235 pounds for the four plats which received lime. The grand averages of water-soluble potash are therefore 0.92% and 0.84% of the amount of K_2O extractable by the concentrated hydrochloric acid from the unlimed and limed soils, respectively; whereas corresponding values of 4.26% and 4.13% obtain as grand averages from the dilute-acid and NH_4Cl extractions.

On the whole, the results from the three soils may be said to indicate a lessened present supply of *available* potash where the soil had been limed. With greater certainty, however, they may be said to demonstrate that the several limings have failed to give any indication of an increased present supply of available potash. Rather definite indications of a repressive effect of liming upon potash availability have been reported by Mooers (15), especially for cowpeas on the Knoxville soil where liming was, on the whole, without benefit unless supplemented by potash. As a possible explanation for such observations, however, it might be contended that liming brought about a potash liberation, particularly during the earlier period, and that such liberated potash was taken from the soil as a result of an increase in the potash content of the crops grown These results could be discussed most interestingly by making detailed comparisons between previously reported yields (15) as influenced by potash in conjunction with lime, and from computations based upon assumptions of the potash removed by the several crops. However, such a detailed study would be too extensive for presentation in a brief symposium paper.

LYSIMETER INVESTIGATIONS

The foregoing potash availability studies may be supplemented by studies from another angle, that of the losses induced by rain water leachings. This method insures greater uniformity of soil because of the thorough mixing of the relatively small mass used in tanks. The determination of the components of the leachings can also be determined with greater precision. There are available two sets of data from the soil used for the extractions reported in Table 3. The first set is given in Tables 4, 5, 6, and 7 and represents the annual outgo from each of 34 tanks over a four-year period. In 16 of these tanks the different lime additions were incorporated only in the upper-half, or zone, of the surface soil, whereas in a parallel series the liming materials were mixed only in the lower zone. In both cases the leachings passed directly from the surface soil through sand filters, without vitiation by subsoil.

In previously reported studies with a similar soil, wherein the unsupplemented lime, or magnesia, additions were mixed throughout the entire mass of soil, it was found that both heavy (9) and economic amounts (13) of the several alkali-earth materials caused a diminished outgo of potassium. In the second contribution it was shown that some increase in potash outgo was obtained through the liberative action of calcium sulfate and magnesium sulfate, apparently as the result of interchange of bases in the *acid* soil. These salts were formed by the solvent action of the sulfate radical—derived from ferrous sulfate, pyrite, and elemental sulfur—upon the native alkali-earth components of the unlimed soil. The hydrogen-ion concentration of the soil was therefore materially increased as a correlary to potash liberation. This is in accord with the hypothesis advanced by Bradfield (1).

But when the immediate, or the potential, acidity of each of these sulfur additions was offset by a constant equivalence of lime plus 2,000 pounds, or more, the effect was to reduce the potash outgo to quantities less than the amount lost from the untreated soil. This observation is directly related to the conditions of the present study, since the nitrates and sulfates formed in the limed upper zone had to pass through the lower *acid* zone before escape to the leaching receptacles. On the other hand, the outgo from the upper zone of the tanks devoid of any additions was comparable to that from the same zone in the tanks which received lime additions to the lower zone, but none to the upper. Hence, the activities of the lower-zone lime incorporations, as delimited to the zone of lime contact, were registered in the respective leachings from the second series.

INFLUENCE OF ZONE ADDITIONS OF HYDRATED LIME UPON OUTGO OF NATIVE POTASH

Table 4 gives the potash outgo from four pairs of hydrated lime incorporations in two zones. The four incorporations were equivalent, respectively, to 250, 500, 1,000, and 2,000 pounds of CaO per 2,000,000 pounds of the loam soil of the plat studies of Table 3. Several points stand out as indications from these data.

The losses from all tanks decreased progressively from the maxima of the first year. The variation in annual precipitations of 51.7 inches, 54.62 inches, 45.56 inches, and 39.71 inches could not entirely account for this progressive decrease.

The outgo from the surface-zone incorporations was greater than

TABLE 4.—*Outgo of potash from a loam soil over a four-year period as influenced by surface-zone and subsurface-zone incorporations of CaO at four rates.*

Tank No.	Treatment: Form	Treatment: Rate of CaO pounds	Treatment: Where incorporated	Pounds of K_2O outgo per 2,000,000 pounds of soil: First year	Second year	Third year	Fourth year	Total	Variation: From untreated soil	Variation: Between upper- and lower-zone effect
80 A & B	None	None	None	28.6	18.3	9.8	7.4	64.1	——	——
81 A	$Ca(OH)_2$	250	Surface	28.7	18.8	12.3	6.6	66.4	+ 2.3	4.9
B	$Ca(OH)_2$	250	Subsurface	24.2	21.2	10.2	5.9	61.5	— 2.6	
82 A	$Ca(OH)_2$	500	Surface	36.5	22.5	8.2	8.0	75.2	+11.1	14.0
B	$Ca(OH)_2$	500	Subsurface	30.0	17.7	8.3	5.2	61.2	— 2.9	
83 A	$Ca(OH)_2$	1,000	Surface	36.4	18.6	11.2	9.2	75.4	+11.3	24.4
B	$Ca(OH)_2$	1,000	Subsurface	24.7	14.5	6.6	5.2	51.0	—13.1	
84 A	$Ca(OH)_2$	2,000	Surface	30.5	20.1	12.9	7.5	71.0	+ 6.9	17.7
B	$Ca(OH)_2$	2,000	Subsurface	24.9	16.3	6.7	5.4	53.3	—10.8	

TABLE 5.—*Outgo of potash from a loam soil over a four-year period as influenced by surface-zone and subsurface-zone incorporations of equivalent amounts of limestone separates and their composites.*

Tank No.	Treatment: Material and fineness	Treatment: Rate of CaO, pounds	Treatment: Where in-corporated	Pounds of K_2O outgo per 2,000,000 pounds of soil: First year	Second year	Third year	Fourth year	Total	Variation: From untreated soil	Variation: Between upper- and lower-zone effect
80 A & B	None	None	None	28.6	18.3	9.8	7.4	64.1	——	——
88 A	Limestone, 10–20-mesh	2,000	Surface	31.9	22.4	9.5	7.0	70.8	+ 6.7	15.7
B	Limestone, 10–20-mesh	2,000	Subsurface	32.0	12.9	5.1	5.1	55.1	— 9.0	
89 A	Limestone, 20–40-mesh	2,000	Surface	30.5	22.3	9.3	9.2	71.3	+ 7.2	10.8
B	Limestone, 20–40-mesh	2,000	Subsurface	28.5	15.2	10.8	6.0	60.5	— 3.6	
90 A	Limestone, 40–80-mesh	2,000	Surface	29.4	20.6	14.3	7.2	71.5	+ 7.4	14.8
B	Limestone, 40–80-mesh	2,000	Subsurface	27.2	15.7	8.3	5.5	56.7	— 7.4	
91 A	Limestone, 80–200 mesh	2,000	Surface	27.2	24.8	13.9	6.5	72.4	+ 8.3	18.8
B	Limestone, 80–200-mesh	2,000	Subsurface	26.0	12.4	9.8	5.4	53.6	—10.5	
87 A	Limestone, composite	2,000	Surface	21.8	32.5	6.1	4.7	65.1	+ 1.0	15.9
B	Limestone, composite	2,000	Subsurface	25.3	11.9	7.3	4.7	49.2	—14.9	

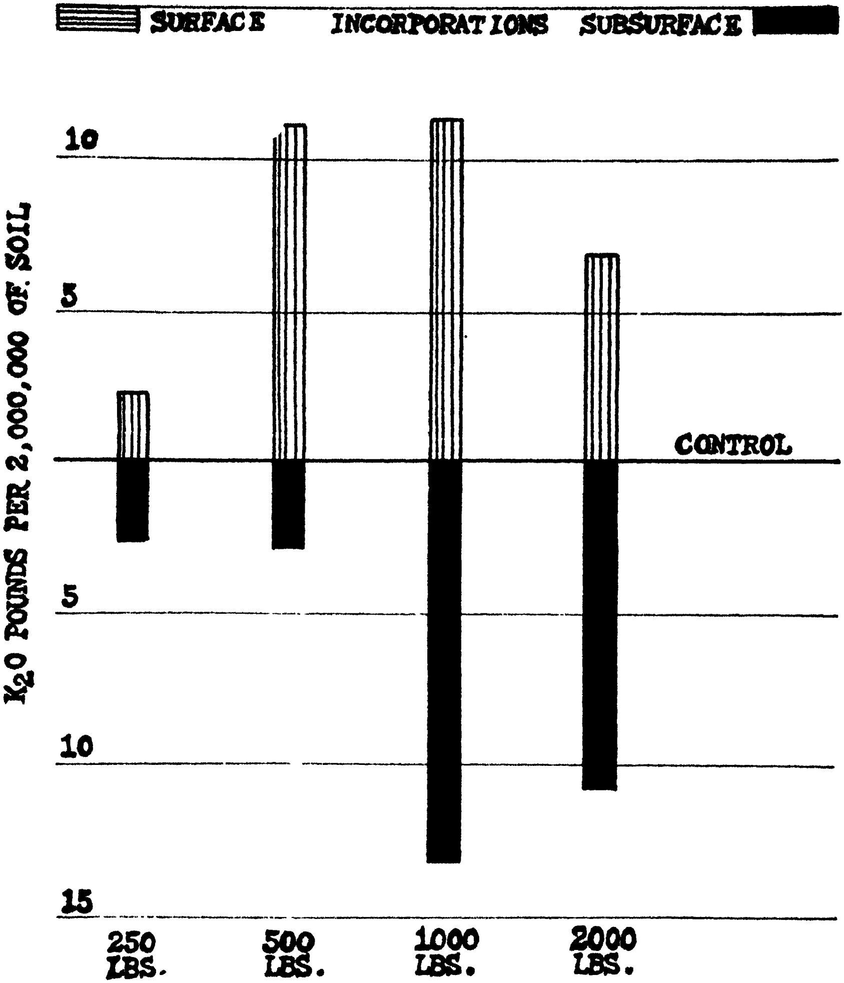

FIG. 1.—Outgo of potash from a loam soil over a four-year period as influenced by surface-zone and subsurface-zone incorporations of CaO at four rates.

that from the lower zone incorporations in 14 of the 16 comparisons and identical in one of the other two cases. The annual and total losses from the tanks whose upper zone received lime were almost always in excess of those from the untreated soil. Since related work with the same soil has demonstrated that its neutral calcium salts will not liberate potassium in the presence of an excess of lime, even though such an excess had been fixed by the soil, it follows that the enhanced outgo of potash was obtained from the lower, unlimed zone through the liberative action of the calcium-salt impregnated leachings from the limed upper zone. This liberative action was of such extent as to more than offset the depression, known by analogy to have been exerted by the lime in the upper zone.

Conversely, the losses from the lower-zone treatments were uniformly less than those from the untreated soil. The zone-effect variations derived from these plus and minus values were quite appreciable for the 500-, 1,000-, and 2,000-pound incorporations. These three treatments were more active than the 250-pound treatment in causing increased potash outgo from the zone which was free from direct contact with the lime and, conversely, in decreasing the potash outgo from the zone throughout which the lime was incorporated. However, these relative activities were not in uniform proportion to the amounts added.

INFLUENCE OF ZONE-ADDITIONS OF LIMESTONE UPON OUTGO OF NATIVE POTASH

In Table 5 are given the results from five surface-zone and five subsurface-zone incorporations of limestone to the soil from which the data of Tables 3 and 4 were obtained. Four separates, 10–20-, 20–40-, 40–80-, and 80–200-mesh, and their composite were used. The relations previously obtained for the caustic lime incorporations also hold for the several limestone separates, in that all surface-zone incorporations caused a potash outgo in excess over that from the control, whereas the outgo from each subsurface-zone incorporation was less than that from the untreated soil. There was also a similar progressive decrease in annual outgo.

Previous contributions have shown that the influence of fineness was an important factor in determining the carbonate disintegration (11) and fixation (12) exerted by this soil. From these findings it seems logical to expect variations as a result of the influence of fineness upon potash outgo. Instead, however, the five incorporations gave comparable results. Furthermore, no variation was shown between the repressions resulting from the 500-pound, 1,000-pound, and 2,000-pound lime incorporations, all of which were quickly absorbed by the soil. Hence the variation between carbonate residuals and the complementary absorptions, as influenced by degree of fineness of the limestone, would not necessarily be reflected in the potash outgo. It has been shown that only 6.5% of the 10–20-mesh limestone had been disintegrated after four years' exposure in the surface zone, as against 51.8% in the lower zone (11). It is the repressive effect of the lower-zone incorporation which is directly registered by the leachings. Hence, it would seem that the minimum amount

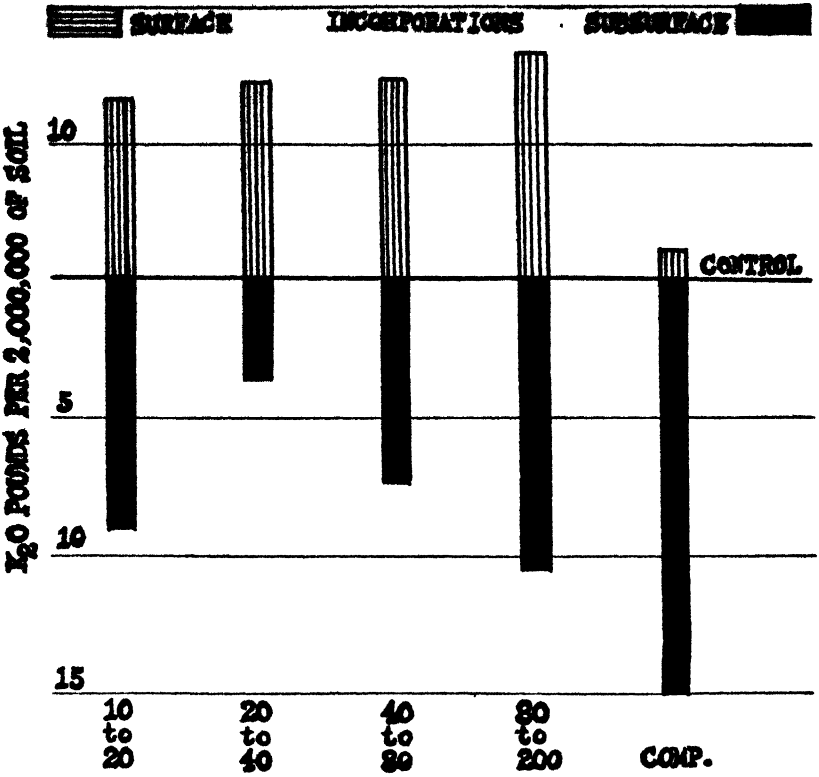

FIG. 2.—Outgo of potash from a loam soil over a four-year period as influenced by surface-zone and subsurface-zone incorporations of equivalent amounts of limestone separates and their composite.

of liming materials which was absorbed by the soil was sufficient to exert the protective effect responsible for lessened outgo of potash. That is, the smaller absorbed fractions of the carbonate separates were sufficient to reduce the H-ion concentration to a point where potash liberation was inhibited.

INFLUENCE OF ZONE-ADDITIONS OF DOLOMITE UPON OUTGO OF NATIVE POTASH

The dolomite series (Table 6) showed the same general tendencies which were shown by the limestone. The differences obtained, especially those for the surface-zone incorporation, are not so extensive, however, as to reflect the reported (11) differences between the speed of the disintegrations of these two limestones.

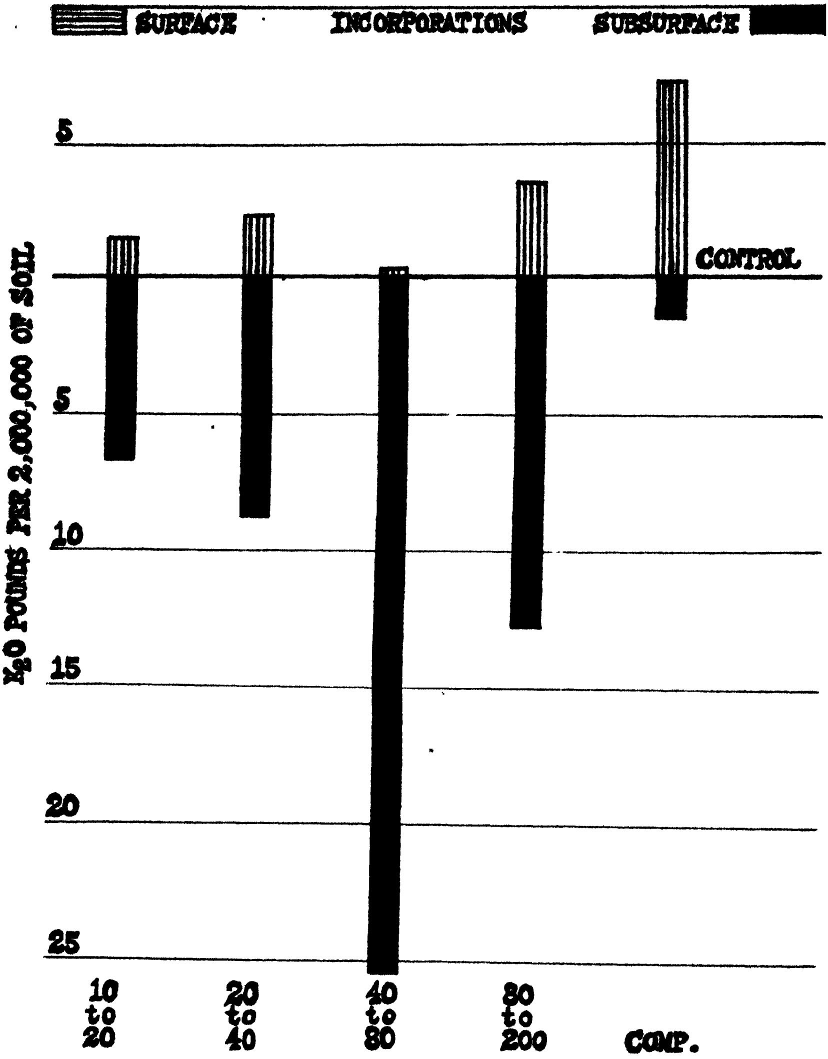

FIG. 3.—Outgo of potash from a loam soil over a four-year period as influenced by surface-zone and subsurface-zone incorporations of equivalent amounts of dolomite separates and their composite.

INFLUENCE OF ZONE-ADDITIONS OF HIGH-MAGNESIC LIMES UPON OUTGO OF NATIVE POTASH

The comparative activities of chemically equivalent incorporations of high-calcic and dolomitic limes are given in Table 7. One dolomitic lime was derived from calcination of a Knox dolomite, whereas

TABLE 6.—*Outgo of potash from a loam soil over a four-year period as influenced by surface-zone and subsurface-zone incorporations of equivalent amounts of dolomite separates and their composites.*

Tank No.	Treatment			Pounds of K_2O outgo per 2,000,000 pounds of soil						
	Material and fineness	Rate of CaO, pounds	Where incorporated	First year	Second year	Third year	Fourth year	Total	Variation: From untreated soil	Variation: Between upper- and lower-zone effect
80 A & B	None	None	None	28.6	18.3	9.8	7.4	64.1	——	——
93 A	Dolomite, 10–20-mesh	2,000	Surface	28.9	17.6	12.8	6.3	65.6	+ 1.5	8.2
B	Dolomite, 10–20-mesh	2,000	Subsurface	27.0	15.1	9.3	6.0	57.4	— 6.7	
94 A	Dolomite, 20–40-mesh	2,000	Surface	26.6	21.1	11.2	7.5	66.4	+ 2.3	11.0
B	Dolomite, 20–40-mesh	2,000	Subsurface	26.9	12.4	8.9	7.2	55.4	— 8.7	
95 A	Dolomite, 40–80-mesh	2,000	Surface	29.5	18.9	8.9	6.6	63.9	— 0.2	25.3
B	Dolomite, 40–80-mesh	2,000	Subsurface	16.6	8.2	8.4	5.4	38.6	—25.5	
96 A	Dolomite, 80–200-mesh	2,000	Surface	26.5	23.9	8.8	8.3	67.5	+ 3.4	16.1
B	Dolomite, 80–200-mesh	2,000	Subsurface	16.1	13.9	14.5	6.9	51.4	—12.7	
92 A	Dolomite composite	2,000	Surface	31.2	19.8	12.3	8.1	71.4	+ 7.3	8.9
B	Dolomite composite	2,000	Subsurface	26.1	18.2	11.2	7.0	62.5	— 1.6	

TABLE 7.—*Outgo of potash from a loam soil over a four-year period as influenced by surface-zone and subsurface-zone incorporations of equivalent amounts of high-calcic and high-magnesic limes.*

Tank No.	Treatment			Pounds of K_2O outgo per 2,000,00 pounds of soil						
	Form	Rate of CaO, pounds	Where incorporated	First year	Second year	Third year	Fourth year	Total	Variation: From unlimed soil	Variation: Between upper- and lower-zone effects
80 A & B	None	None	None	28.6	18.3	9.8	7.4	64.1	——	——
84 A	$Ca(OH)_2$	2,000	Surface	30.5	20.1	12.9	7.5	71.0	+ 6.9	17.7
B	$Ca(OH)_2$	2,000	Subsurface	24.9	16.3	6.7	5.4	53.3	—10.8	
85 A	CaO-MgO[a]	2,000	Surface	26.7	17.5	6.7	6.9	57.8	— 6.3	4.2
B	CaO-MgO	2,000	Subsurface	23.9	14.8	8.6	6.3	53.6	—10.5	
86 A	CaO-MgO[b]	2,000	Surface	26.3	17.1	7.8	4.6	55.8	— 8.3	8.9
B	CaO-MgO	2,000	Subsurface	21.4	12.0	7.2	6.3	46.9	—17.2	

[a] Calcined dolomite.

[b] Mixture of separately calcined CaO and MgO.

the other was made by mixing CaO and MgO in the proportions found in the natural stone. The leachings from these two alkali-earth mixtures differed from those yielded by the hydrated lime, limestone, and dolomite, in that the mixed oxides gave a decreased potash outgo for *both* methods of incorporation. But, even with a depressive effect exerted in both zones, that found in the lower zone was much the greater. The explanation for the difference between the upper-zone activity of these high-magnesic limes and that exerted by the other three liming materials is probably a complicated one involving differences between the hydrolysis of absorbed CaO and that of absorbed MgO and is beyond the scope of this paper.

CONSERVATION OF ADDED POTASH AS INFLUENCED BY LIMING

In the foregoing discussion of potash outgo the influence of liming upon *native* potash has been considered (a) as to its repressive effect in the same zone where the calcium-magnesium absorptions had taken place and (b) from the angle of basic interchange brought about by soil-generated alkali-earth salts in the underlying acid zone which had not been limed but which was subject to the action of leachings impregnated with calcium salts. The data of Table 8 represent a study of the influence of hydrated lime, two limestone separates, and two dolomite separates upon the fate of potash added by means of green clover cuttings. The green clover was air-dried and then ground. It was used at the rates of 2 and 8 tons of moisture-free material per 2,000,000 pounds of soil. These additions furnished 70 pounds and 280 pounds of total K_2O, respectively, all of which was water-soluble. In this series, which has been going less than two years, the soil used was of the Cumberland loam type reported upon in Tables 3, 4, 5, 6, and 7. The limestone and dolomite additions were of 100-mesh and 40–50-mesh fineness. All additions were incorporated throughout the full-depth of soil and the leachings passed directly through sand filters into the collection containers. The lysimeters used in this study have been described and illustrated (11).

The data of Table 8 represent averages of two tanks for each treatment. The results from the control group of 10 tanks, 83 A and B to 87 A and B, show that each of the five unsupplemented lime incorporations has exerted a depressive effect upon the outgo of native potash. This observation is in harmony with all of our previous findings.

The 2-ton green-manure controls without lime, 81 A and 81 B, gave a potash outgo of 34.5 pounds in excess of that from the un-

TABLE 8.—*Outgo of potash as influenced by equivalent additions of Ca $(OH)_2$, limestone, and dolomite of 40–50-mesh and 100-mesh fineness mixed throughout soil, with and without green manure.*[a]

Tank No.	Treatment 2,000 pounds CaO =c= as	Green manure	Pounds of K_2O outgo per 2,000,000 pounds of soil: Actual	Decrease below untreated soil	Decrease below respective control
80 A & B	None	None	59.3	——	——
83 A & B	$Ca(OH)_2$	None	44.9	14.4	——
84 A & B	Limestone, 100-mesh	None	45.5	13.8	——
85 A & B	Limestone, 40–50-mesh	None	47.7	11.6	——
86 A & B	Dolomite, 100-mesh	None	43.2	16.1	——
87 A & B	Dolomite, 40–50-mesh	None	52.4	6.9	——
81 A & B	None	2 tons	93.8	+34.5	——
88 A & B	$Ca(OH)_2$	2 tons	54.4	4.9	39.4
89 A & B	Limestone, 100-mesh	2 tons	57.1	2.2	36.7
90 A & B	Limestone, 40–50-mesh	2 tons	64.8	+ 5.5	29.0
91 A & B	Dolomite, 100-mesh	2 tons	59.3	.0	34.5
92 A & B	Dolomite, 40–50-mesh	2 tons	50.3	9.0	43.5
82 A & B	None	8 tons	158.3	+99.0	——
93 A & B	$Ca(OH)_2$	8 tons	119.5	+60.2	38.8
94 A & B	Limestone, 100-mesh	8 tons	142.0	+82.7	16.3
95 A & B	Limestone, 40–50-mesh	8 tons	120.7	+61.4	37.6
96 A & B	Dolomite, 100-mesh	8 tons	129.7	+70.4	28.6
97 A & B	Dolomite, 40–50-mesh	8 tons	146.0	+86.7	12.3

[a] Acknowledgment is due Dr. R. M. Barnette, formerly of the Tennessee Experiment Station, for analytical work essential to the inauguration of the project reported upon in this table.

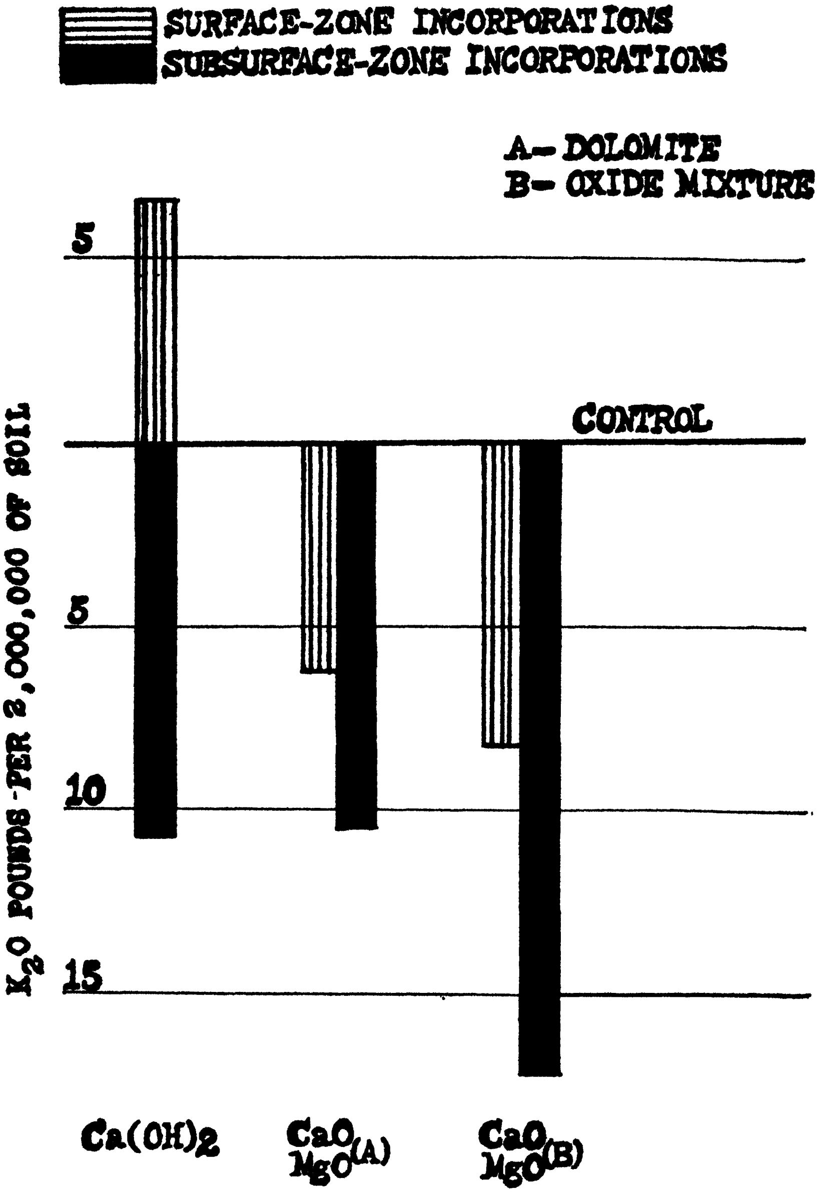

FIG. 4.—Outgo of potash from a loam soil over a four-year period as influenced by surface-zone and subsurface-zone incorporations of equivalent amounts of high-calcic and high-magnesic limes.

treated controls 80 A and 80 B. This increase obtained from the unlimed manure additions is equivalent to 49.3% of the total added potash, all of which was soluble in water. But in the 10-unit group which received the 2-ton green-manure additions, i. e., 70 pounds of K_2O, with one of each of the five lime supplements, only one treatment showed any increase (5.2 pounds) in potash outgo as against the 34.5-pound increase from the unsupplemented clover tanks. As an average this 10-unit clover-2-ton-lime group gave a potash outgo 2.1 pounds less than that from the untreated tanks and 36.6 pounds less than that from the group which received unsupplemented green manure incorporations.

The average K_2O outgo from the two tanks which received 8 tons of green manure without lime was a 158.3 pounds. The loss from 8 tons of green manure *alone* was therefore 99 pounds over the outgo from the untreated soil. This observation is of interest in connection with the findings of Vandecaveye (19). Had this loss been directly proportionate to that from the 2-ton addition it would have amounted to 138 pounds, but the 10 tanks which received the same amount of green manure plus the several single additions of liming materials gave an average outgo of only 131.6 pounds. From these group averages the repression, or conservation, exerted by the lime incorporations was therefore 26.7 pounds. The loss and conserved fractions of the 70-pound K_2O addition from 2 tons of manure were 34.5 and 35.5 pounds, respectively, or 49.3% and 50.7%. The corresponding values from the 280-pound incorporation were 99 pounds and 181 pounds, or percentages of 35.4 and 64.6, respectively.

Every lime-2-ton-clover unit in this series gave up decidedly less potash than the amount yielded by the unsupplemented clover, and only one unit showed more potash outgo than that which went from the untreated soil. In the 8-ton group, however, the potash outgo from each lime-clover unit was greater than that from the *untreated soil*, yet decidedly less than that from the soil which received 8 tons of clover without lime. Leguminous green manure incorporations carry considerable lime and tend to produce alkaline conditions in the soil, so that the heavier incorporation produced somewhat the same effect as that produced by lime additions.

These findings justify a new viewpoint, that of potash *conservation*, as differing from the previously discussed question of potash liberation. The potash added through the clover incorporations is not to be considered as having come into the soil system only so rapidly as the clover underwent decomposition, since all of the added potash was water-soluble. The tanks were free of plant growth and the two

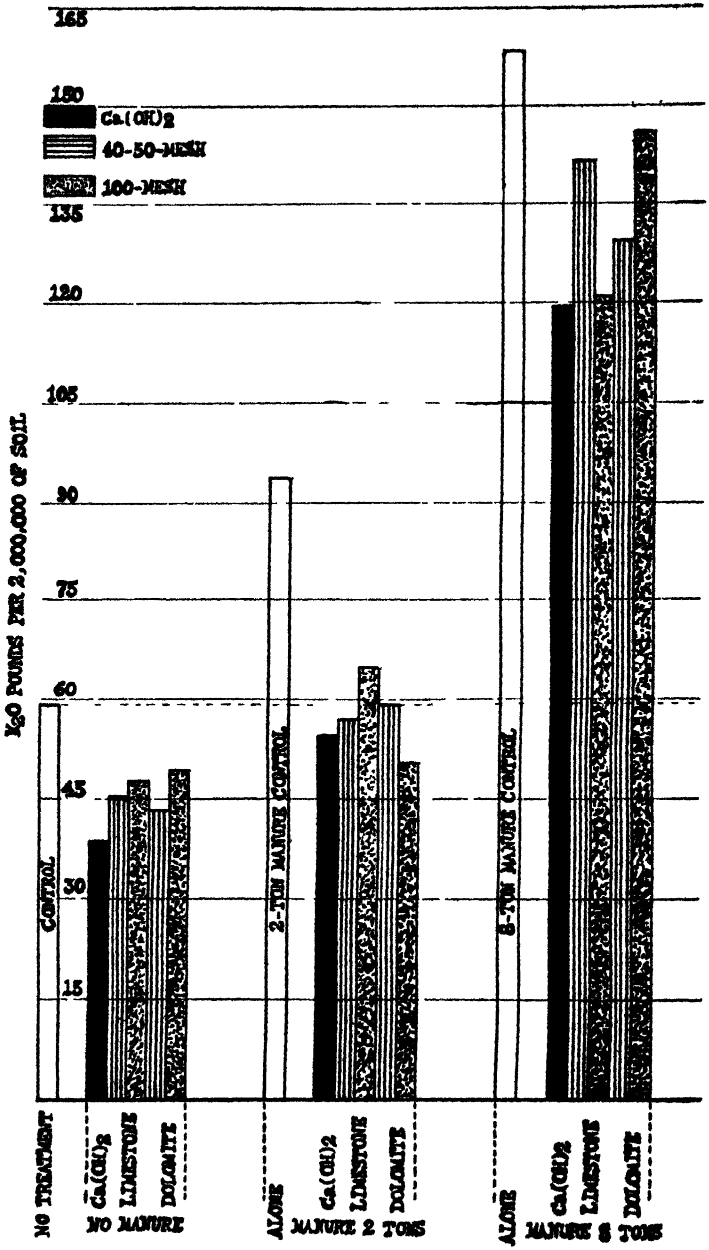

FIG. 5.—Outgo of potash as influenced by equivalent incorpoations of $Ca(OH)_2$, limestone, and dolomite of 40- to 50-mesh and 100-mesh fineness mixed throughout soil, with and without manure.

group averages of 36.6 pounds and 26.7 pounds for the 2-ton and 8-ton manurial incorporations, therefore, represent the amounts of potash which the liming materials prevented from passing into the subsoil, as a result of the leaching action of a 43.25-inch rainfall. The fate of this clover-derived potash may be considered as identical with that added as soluble manurial salts. It is therefore held by the soil less tenaciously (3) than is the native potash present as undisintegrated minerals and is undoubtedly available to plants. Instead of assuming that the added potash which is conserved against normal rain water leaching is resistant to the feeding power of plants, it may be assumed that healthy, vigorous plants growing in a limed soil will vigorously attack and assimulate this loosely bound conserved potash.

SUMMARY

It is pointed out that the results of laboratory interchange studies have served as the basis for unjustified assumptions that potassium will be liberated by calcium in the practice of liming. Evidence is cited to show that a neutral salt of calcium may liberate potassium to the leachings from an acid soil, but that the reverse effect results when supplementary additions of CaO or MgO are made.

Studies were made of the present availability of the potash of three soils which had been subject to the influence of liming in plat studies extending over respective periods of 7, 17, and 21 years. Distilled and carbonated water, HCl (1.115), and 0.2 N HCl digestion and leachings to equilibrium with 0.05 N HCl and with N/1 NH_4Cl were used to measure the present availability of native and added potash as influenced by liming.

In general the two dilute acid and NH_4Cl procedures gave comparable results without consistently showing a definite effect from liming, although indicating increase in potash reserve supplies where potash had been added. The two aqueous extraction procedures did indicate a definite decrease in availability of native and added potash as the result of liming. No indication of potassium liberation was adduced in any case. The extraction studies were in line with the yields from those plats as given by Mooers.

From a four-year supplementary lysimeter study upon the influence of surface and subsurface incorporations of $Ca(OH)_2$ at four rates, high-magnesic lime, and five limestone and five dolomite constants upon native potash it was demonstrated that: (a) The surface-zone incorporations gave consistently greater yields, whereas the subsurface incorporations gave consistently lower yields, of leachable potash than were given by the untreated soil; (b) neutral calcium salts exerted no liberative effect in the zone of alkali-earth

incorporation; (c) calcium salt leachings effected a potash liberation in the lower untreated acid zone; (d) progressive decreases in annual outgo were found; and (e) high-magnesic limes caused diminished potash outgo, irrespective of zone of incorporation.

From a second supplementary lysimeter study relative to the influence of hydrated lime, that of ground limestone and that of dolomite (all equivalent to 1 ton of CaO), upon the fate of water-soluble potash added through clover cuttings, where all additions were mixed throughout the full depth of soil, it was found that: (a) Each unsupplemented alkali-earth addition resulted in a potash outgo less than that from the control; (b) the several incorporations so "fixed" the 70-pound potash increment from 2 tons of clover as to give an average outgo less than that from the no-clover soil; and (c) the 99-pound increase in potash outgo from the unsupplemented 8-ton clover incorporation, which supplied 280 pounds of K_2O, was reduced to an outgo of only 72 pounds as an average from the five lime treatments.

It is pointed out that, when pH values indicate excess of H-ions, potash liberation is effected by neutral calcium salts and that the reverse, potash fixation, is brought about when H-ion concentration is greatly reduced, or superseded by OH-ion concentration, if the OH concentration is not so excessive as to induce hydrolysis of native potassic complexes, as the result of the practical liming of these particular soils.

As differing from the interchange between native potash for added lime, through zone-of-incorporation conditions which permit such interchange, a new viewpoint is advanced, that of the value of liming in its capacity to conserve soluble potash additions in a form most probably available to plants, yet resistant to excessive loss through normal leaching.

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5. POTASH IN RELATION TO QUALITY OF CROP[1]

Geo. L. Schuster[2]

The pioneer efforts of agronomists in experimental work with crops were aimed toward increased acre production and means of cultivating greater areas. This attitude has persisted until recently and has only been changed by the fact that there has been an excess production of certain crops. These large surpluses have depressed the prices received by the grower and he cannot market his crops profitably. The increased yields in many instances have not been sufficient to pay for the additional cost of production The demands for the lower grades of a product have diminished because there has been such a large quantity production, thus making the better qualities or grades stand out.

In recent years plant breeders have endeavored to produce a better product or one possessing an outstanding quality, such as increased protein content of wheat; variation in the oil or protein content of corn and oil in soybeans; increase in the sugar content of sugar beets; quality and length in fiber of cotton, flax, and hemp; improved quality of potatoes; and better quality in leaf, type, burn, etc., of tobacco. These have all called for extensive investigations and some valuable results have been obtained

Walster (36)[3] has classified these factors as internal factors controlling crop quality. There are also external factors that influence the quality of product. These may be divided into four headings, *viz.*, (a) climate, (b) soil, (c) fertilizers, and (d) husbandry

For a general discussion covering the external factors the reader is referred to the smyposium on "Controlling the Quality of Crops" in Vol. 18, pages 618–703, of this Journal. It is the purpose of the writer to discuss at this time only fertilizers in relation to quality of crop with special reference to potash.

Potash is one of the essential elements for plant growth. It must perform certain vital functions in plant nutrition. The most important of these, it would appear, is its relation to the production of carbohydrates, starch, sugar, and cellulose within the plants. Hence crops that are rich in these constituents, such as mangels, sugar beets, potatoes, sunflowers, corn, fruits, and leguminous plants, would be expected to respond to potash fertilizers. Not all soils need potash. Crops grown on soils that contain plenty of potash will not respond to potash treatment. Responses from potash are generally obtained on sandy and gravelly loams, calcareous soils, and soils rich in vegetable matter, as the mucks and peaty loams. It is on the aforementioned types of soil and with the crops specified therefore, that one must look for indications of the effect of potash upon the quality of crop.

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[1] Paper read as a part of the symposium on "Potash" at the meeting of the Society held in Washington, D. C., November 19, 1926.

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[3] Reference by number is to "Literature Cited," p. 515.

The writer has found very little reference to the quality of the crop in reviewing the literature upon the subject. Nearly every product is reported in quantity of crop. There is not any definite measure for the quality of a crop, such as there is for the quantity of the crop. The market grades for corn and small grains might be used as a basis for indicating quality, but they do not indicate the protein content and that may represent quality to some consumers. Soundness may represent quality for some products, plumpness for others, analysis for others, size for others, and maturity for others. Quality of a crop may also be measured by two or more different methods depending upon the demands of the consumer.

A discussion of the effect of potash upon the quality of some of our leading farm crops follows.

POTATOES

Some of the early work with potatoes is very conflicting as to results. Jordan (18) states that sulfate of potash produced more dry matter and more starch in potatoes than muriate on fertilized plats, but that similar results were obtained on the corresponding unfertilized plats adjacent to the fertilized ones, thus diminishing greatly the value of the results. Scovell (29) states that the effect upon the quality of the potato is the same whether sulfate or muriate of potash is used with nitrate of soda and super phosphates. Results obtained in Massachusetts (22) show an average of 92% marketable potatoes with muriate of potash in the fertilizer mixture and 96% with sulfate of potash in the mixture. Mills (23) obtained similar results in later investigations. Davidson (7) states that potatoes grown with muriate of potash contain less dry matter but slightly more starch than those grown with sulfate of potash. Hills (15) states that potatoes grown with muriate contain less dry matter and starch and more non-starchy carbohydrates than those grown with sulfate of potash. Voorhees (35), Scovell (29), and Jenkins (17) report somewhat larger crops from muriate than from sulfate and generally a more watery, less starchy potato.

Woods (38) conducted some investigations on the effect of potash upon the percentage of merchantable potatoes. The results are given in Table 1.

TABLE 1.—*Effect of potash on percentage of merchantable potatoes, Maine Experiment Station.*

Fertilizer	Merchantable tubers %
No potash	95.4
No potash, common salt	97.1
2% potash	97.6
5% potash	97.9
8% potash	97.7

It is evident that 5% potash produced the most marketable potatoes.

Slate and Brown (32) conducted some investigations on the effect of potash upon the size of potatoes. A machine grader was used and the percentage of the total yield of potatoes over 1 7/8 inches is given in Table 2

TABLE 2.—*Effect of potash on size of tubers, Storrs Experiment Station.*

1915-16		1917-18	
Pounds potash per acre	Percentage of total over 1⅞ in.	Pounds potash per acre	Percentage of total over 1⅞ in.
—	——	0	78.7
—	——	40	90.6
80	91.0	80	93.8
140	90.8	140	95.6
200	92.0	200	96.0

The authors state that potash up to 80 pounds per acre consistently increases the percentage of marketable tubers. In 1917 18 there was a slight progressive increase up to 200 pounds of potash, but it is not significant after the 80-pound application is reached.

Lipman and Blair (20) state that when "primes" alone are considered the average is slightly better with 6% potash than with 10% in a 1,600-pound application of a complete fertilizer. A summary of their findings is given in Table 3.

TABLE 3.—*Showing percentage of "primes" for various fertilizer treatments, New Jersey Experiment Station, 1920 to 1922, inclusive.*

Fertilizer application per acre	Percentage "primes"
1,600 pounds 4-8-0	84.5
1,600 pounds 4-8-3	80.6
1,600 pounds 4-8-6	88.5
1,600 pounds 4-8-10	87.1
1,600 pounds 4-8-0 2½ tons greens and marl	85.4

The effect of the various carriers of potash upon the starch content of sweet potatoes has been reported upon by Shiver (31). He says, in part, that the greatest amount of starch per acre is produced by kainit, somewhat less by sulfate, a smaller amount by silicate, and the smallest amount by muriate of potash.

It would seem from this brief review of the literature that potash produces a sizeable, marketable potato; that sulfate is more desirable than muriate because of its influence upon the starch content; that 6% potash in an application of 1,600 pounds per acre of fertilizer or its equivalent is about the right amount.

SUGAR CROPS

Cook (6) in some early investigations with sorghum sugar cane says that the yield of sugar per ton of cane is 20% greater with sulfate than with muriate of potash. Muriates, too, if taken into the sorghum juice interfere with the crystallization of the sugar.

Saillard (26) in summarizing experiments conducted in France says that generally potassic fertilizers gave good results in regard to richness, purity, and yield of sugar beets. Kainit gave better results than chlorid or sulfate of potash. Malpaux (21), working with potash fertilizer in Pas-de-Calais, found that sulfate is suited to beets. Headden (13), working on the deterioration in the quality of sugar beets, found that it was due to nitrates formed in the soil and that the quality was affected beneficially by applications of potash and phosphoric acid.

Quality in sugar crops is measured by the percentage of sugar contained in the crop and by the purity of the juices. Sulfate of potash seems to produce the desired results.

GRAIN CROPS

The Delaware Station (28) has published 16 years' results on the effect of various fertilizers on the percentage of sound corn. The results are given in Table 4.

TABLE 4.—*Effect of fertilizers on soundness of corn, Delaware Experiment Station.*

Treatment	Percentage of sound corn	
	Limed	Unlimed
No treatment	59.5	60.8
Nitrate of soda, 125 pounds	62.0	64.9
Acid phosphate, 250 pounds	60.6	63.9
Muriate of potash, 75 pounds	84.1	73.2

It is evident that on this soil, a sassafras silt loam, potash is the contributing factor toward a high percentage of sound corn.

Woll (37) has found that potash did not give as high a percentage of shelled corn as did phosphoric acid on Wisconsin marsh soils. A summary of his findings is given in Table 5.

TABLE 5.—*Component parts of corn plant at harvest time, Wisconsin Experiment Station.*

Treatment	Percentage of shelled corn	Cobs	Dry straw
Phosphoric acid, potash	26.6	8.7	64.7
Lime (marl)	28.1	7.8	64.1
Potash	26.3	8.6	65.1
Farmyard manure	26.8	8.1	65.1
Phosphoric acid	28.7	8.8	62.5
None	24.2	7.4	68.4

Hutcheson and Wolf (16) state that of the commercial fertilizers used alone acid phosphate was the most efficient in increasing the yield, percentage of matured ears, percentage of marketable grain, and shelling percentage; but that combinations of dried blood, acid phosphate, and muriate of potash were more effective in increasing yield and quality of corn than acid phosphate alone; and conclude that the right proportions of ammonia, phosphoric acid, and potash are more important in regard to yield and quality than any single plant nutrient.

Ames (2), et al, in working with wheat, found that increasing the nitrogen supply without increasing the potassium and phosphorus lowered the quality of the grain below that of the untreated soil. Potassium improved the quality so far as plumpness of kernel was concerned. Later investigations reported by Thatcher (34) show that the addition of nitrogen increased the percentage of shriveled kernels, while phosphorus markedly increased plumpness and potassium to a less degree.

The author (28) has reported results with various fertilizers on wheat showing that nitrate of soda produces wheat with an average test weight of 52.5 pounds per bushel, acid phosphate 55.9 pounds, and muriate of potash 56.7 pounds. A combination of acid phosphate and potash produces wheat weighing 58 pounds per bushel, a complete fertilizer 58.8 pounds. If the wheat from these plats were graded according to the United States grain standards on test weight alone, i. e., granting that other factors did not lower the grade established by the test weight, they would grade 5, 4, 2, 2, and 2, respectively. The average difference in price of No. 2 wheat and No. 5 wheat is 9 cents. This shows how quality may affect price.

Headden (14) states that excess potash causes yellow berry in wheat or soft kernels of lighter color, but that additional nitrates resulted in hard wheat. Evidently there was plenty of potash in this soil for a normal crop, but it was not balanced with nitrates.

Corn and wheat has been discussed as to quality of grain. Quality has been measured by percentage of shelled corn, sound corn, plumpness of wheat, and test weight per bushel. The evidence is conflicting as to the value of potash. However, where potash produced negative results the author's interpretation is that there was sufficient potash in the soil for normal growth. As has been stated the effects of potash on the quality of crop can only be shown on soils deficient in potash and with crops that demand it.

TOBACCO

The investigations that have been conducted with tobacco are voluminous and no attempt will be made to review all the literature available but simply to bring out some of the salient points in the literature in reference to quality. Quality in tobacco is a broad attribute and may be measured in different ways, depending upon the purpose for which the crop is grown, i. e., wrapper, filler, pipe, cigarette, or chewing. For example, recent work by Green (12) with sun-cured tobacco has not shown potassium sulfate to be superior to potassium chloride since this tobacco is used largely for chewing and any adverse effect that potassium chloride would have on the burning quality would be unimportant.

Ames and Boltz (1) report that smoking tests of cigars from several lots of tobacco show that the quality of tobacco is impaired where muriate of potash is used in the fertilizer. Tobacco with a low chlorine content has a good fire-holding capacity in contrast with tobacco containing excessive amounts of chlorine due to fertilizer treatments. All the tobaccos with a high chlorine content had a black, charred ash which in some instances did not cohere with the ash of the binder and wrapper with the result that the ash of the binder and wrapper shattered easily. The average length of time the cigars made from tobacco from muriate treated plats held fire was approximately half that for tobacco from plats treated with sulfate or nitrate of potash. Potassium when used in other combinations than the chloride improved the quality of the tobacco. In concluding they say that, "Variations in flavor, aroma, and fire-holding capacity are not due entirely to the presence or absence of any one compound, but are more or less dependent upon the total constituents of the tobacco."

Patterson (24) states that muriate of potash should not be used as a fertilizer as it always produces tobacco with a poor burning quality and a bad ash, and that sulfate of potash produced a better burning tobacco than any other of the potash salts. Lime and magnesia compounds and sulfate of potash and magnesia (low grade sulfates) in most cases produced tobacco of a poor burning quality.

Frear (9) came to the conclusion that the use of commercial fertilizers containing potash in the form of sulfate or carbonate gives tobacco of better burning quality than does stable manure and that there are indications that the imperfections in the burn of the tobaccos grown on these soils cannot be altogether removed by care against chlorine injury alone. Earlier trials in Lancaster County (25) indicated that where potassium magnesium carbonate replaced potassium sulfate the leaf was more uniform and of better texture and burned slightly better without impairing the flavor or aroma.

Anderson (3) states that comparison during sorting placed tobacco from the sulfate plats as the poorest of all. The leaves were inclined to be yellow, boardy, and lacking in life and elasticity. The plats having carbonate of potash alone were of better quality.

Other references could be cited, but they are of the same general nature. For a more complete discussion the reader is referred to the review given by Steece (33).

Carpenter and Allen (5) state that it often happens that fertilizers made wholly with sulfate as a source of potash will show more chlorine than the lawful amount due to its presence in other materials used in the formula. They tested several brands of cigars varying in price from 2½ to 25 cents and also some pipe tobaccos and cigarettes and summarized their data as follows: (a) Cigars contain more chlorine than is generally supposed. (b) The average smoking tobacco contains less chlorine than cigars. (c) Excessive amounts of chlorine are not desirable, but a relatively large percentage does not necessarily produce a bad burn. (d) Chlorine may injure the burning quality, but it is seldom that tobacco contains enough to do serious harm. (e) There is no evidence to support the popular notion that small amounts of chlorine in fertilizers will injure the quality of the tobacco grown and the existing prejudice against fractional percentages of this element is not justified. (f) The chlorine content of tobacco grown in different localities varies. This would appear to be due, in part at least, to the variation in the amount present in the soil.

The results as to the use of sulfate or muriate of potash on tobacco with reference to quality do not all agree. There may be several reasons for this, some of which are (a) difference in soil conditions, (b) nature of impurities carried by the sulfate or muriate, (c) nature of impurities carried by other fertilizers in the mixtures.

Garner (10) states that, "As regards combustibility of tobacco, potassium is the one element which catalyses the combustion process so that obviously without an adequate supply of this element leaf tobacco cannot possess good burning qualities. Potassium has a further favorable effect in that its salts act as a cementing material giving coherence to the ash. As regards effects on combustion of the acid radicles of potash salts, such as the chloride, sulfate, and phosphate, all of these tend to interfere with the functioning of potassium in catalyzing the combustion process. It is undoubtedly true, however, that the chlorid radicle is far more injurious in this respect than other acid radicles. On the other hand, there are many factors influencing combustibility of tobacco so that close correlation is not always found between chlorine content and the combustibility. From the standpoint of combustibility, the aim in fertilizing tobacco with potash salts should be to afford the plant an opportunity to absorb potassium in liberal supply with a minimum accumulation in the leaf of unassimilated acid radicles, namely, chloride, sulfate, and phosphate."

SOYBEANS

Goessman (11) states that sulfate of potash and magnesia on leguminous crops gave, in most instances, better results than muriate of potash. Tests with soybeans showed that potash had the greatest effect upon the increase and quality of the crop. Brooks (4) says that on all soils with good retentive qualities and moisture sulfate of potash should generally be preferred to muriate or kainit, not only for soybeans, but for clovers and with little doubt for all other legumes as well.

Lipman and Blair (19) have reported that where soybeans are inoculated and furnished with lime and phosphate a good growth is made and a high percentage of nitrogen accumulated up to the time the pods are half filled (hay state) without the aid of readily soluble potash compounds.

The author in some early work with soybeans at the Delaware

TABLE 6.—*Effect of fertilizers on maturity of soybeans, Delaware Experiment Station, 1921–1925.*

Treatment	Average precentage of mature beans	
	Limed	No lime
None	91.5	96.9
Nitrate of soda (N)	92.9	96.7
Acid phosphate (P)	86.8	93.1
Muriate of potash (K)	98.4	99.7
N, P	86.5	94.2
P, K	97.5	99.3
N, K	99.1	98.5
N, P, K	98.7	98.9
Manure	97.7	98.0

Station reached the conclusion that the presence of muriate of potash in fertilizers for soybeans brings the beans to maturity. This work has been continued and the later findings are reported in Table 6.

The Wilson soybean was used in these tests and the immature bean was identified by its small size, shriveled nature, and often a red color. It has been noted that the Wilson bean is of a wine-red color before it passes into the mature black color.

In examining Table 6 it will be noted that wherever muriate of potash occurs in the fertilizer there is a higher percentage of mature beans. It is thought to be the potash in the manure that gives a high percentage of mature beans since there is not much evidence that it is nitrates.

Fellers (8) states that, "Immature and small seeds are lower in oil content than mature seeds. This may be explained by assuming that reserve carbohydrates in the seeds have not become fully transformed into oil."

Maturity in soybeans, then, indicates quality because the oil content of soybeans is one of the important properties. There may be some doubt as to what form of potash to use on soybeans, but probably only soil type tests will answer this question. Source tests at Massachusetts indicate that sulfate of potash produces the most desired results. Other tests reported have been with muriate of potash only.

SUMMARY

The methods of measuring quality varies with the crop and the purpose for which the crop is grown. Quality depends upon the market demands and in many instances there are no standards with which to measure quality.

Evidence has been gathered from literature indicating that potash is an important element in producing quality in potatoes, sugar crops, corn, wheat, tobacco, and soybeans. The evidence is not clear as to just what form of potash produces the most desirable quality in every case. In some cases potash does not have any effect upon the quality of the crop grown and in such cases it is to be supposed that there is plenty of potash available in the soil. The problem then becomes one of providing a balanced ration by supplying other plant food needed. An example of this is the supplying of nitrates in order to obtain hard wheat in Colorado.

Conflicting results in many cases may be due to the impurities carried by the potash fertilizers or to variation as to the kind and amount of impurities carried by a given potash fertilizer. There is a need of some well-defined investigations along this line.

A plant may need the element potassium in order to produce a high quality product, but the potassium may be supplied in a form that carries an acid radicle that is inhibitive to the proper growth and development of the plant. These acid radicles may be chlorid, sulfate or phosphate in the most commonly used potassium salts. A small percentage of any or all of these acid radicles may not inhibit the production of a high quality product or one of these acid radicles may be inhibitive and the remainder harmless. Investigations are needed as to the relation of the quality of product produced with these various acid radicles in potassium salts and the percentage of each that is permissable.

The results that have been reported were carried on with various soil types. The properties and reactions of these soil types are not all the same. Some soils may possess properties that counteract the undesirable reactions of impurities in potassium salts or fertilizer mixtures, while others do not possess such properties. Likewise, the harmful effects of certain of the acid radicles may be counteracted by the properties of some soils and not by others. It is important, therefore, to consider the soil type in planning an investigation of this nature, and in making recommendations to make them only for the soil type upon which the study has been made.

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SYMPOSIUM ON "CROP ROTATION"

Leader: W. W. Weir, Bureau of Soils, U. S. Department of Agriculture.

Introductory remarks by the Leader.

1. "Crop Rotation in Relation to Soil Productivity." T. C. Johnson, Virginia Truck Experiment Station.
2. "Some Principles Involved in Crop Sequence " Firman E. Bear, Ohio State University.
3. "Legumes and Grasses in Crop Rotation." T. L. Lyon, Cornell University.
4. "Crop Rotation in Relation to Agriculture in the Corn Belt." A. T. Wiancko, Indiana Agricultural Experiment Station.
5. "Crop Rotation in the Great Plains Area." H. L. Walster, North Dakota Agricultural Experiment Station.
6. "Crop Rotation in Relation to Southern Agriculture." M. J. Funchess, Alabama Polytechnic Institute

Concluding remarks by the Leader.

CROP ROTATION[1]

W. W Weir[2]

Modern crop rotation was established about the year 1730 in England. In general it consists of a cultivated or intertilled crop, a small grain, and a grass or leguminous crop grown in the order named. Nearly 200 years have passed since Lord Townshend demonstrated the benefits of the Norfolk rotation, a cropping system which is used as a standard even now.

The famous Norfolk four-course rotation, consisting of turnips, barley, clover, and wheat, grew out of the experiences of practical farmers covering a period of several thousand years. In the Norfolk rotation, the idea of growing crops with clover came from Flanders, and the idea of intertillage was the contribution of Jethro Tull.

This symposium has been planned with a view to bringing together the facts which have been found out since modern rotation was established, with the hope that a better understanding may be gained of crop-rotation principles.

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[1] Introductory remarks by the Leader of the symposium on "Crop Rotation" at the meeting of the Society held in Washington, D. C., November 19, 1926.

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1. CROP ROTATION IN RELATION TO SOIL PRODUCTIVITY[1]

T. C. JOHNSON[2]

The early English colonists on their arrival in North America found a more or less well-developed system of agriculture practiced by the native tribes. Roger Williams states that the Indians in Rhode Island followed a system of growing corn and beans in which the corn was planted in May, after it had attained a height of 3 or 4 inches, beans were planted by the hills of the corn, the corn stalks thus forming supports for the bean vines. Clean cultivation was given. Especial care was observed to remove all weeds or other superfluous vegetation. A plat of land would be cultivated with this one-season intercropping rotation for a number of years; but when productivity fell below a satisfactory point, the land would be "turned out" and a new field cleared from the forest

The Indians in eastern Virginia and eastern North Carolina seemed to have devoted their agricultural energies largely to the production of corn. John Smith states that most of the lands of the coastal plain regions of Virginia and the Carolinas were very heavily wooded with pine trees and undergrowth of oak and an occasional interchain of grape vines. These lands were naturally very productive. The Indians would clear them of trees by the use of fire. They would then plant the corn in hills about 4 feet apart, planting three grains to the hill When the corn had attained a height of approximately 3 feet, the soil was drawn to the plants with crude implements, thus forming a mound around each hill The individual field would be used for a long number of years; but when productivity fell below a satisfactory point, another field would be cleared from the forest and farming operations started anew. It is stated that the natives frequently fertilized their corn by burying a fish obtained from the nearby rivers under each hill before planting.

Edmund Ruffin in his essay on Calcareous Manures, published in 1832, states that the agriculture of eastern Virginia at that time had reached a very unsatisfactory state A three-year rotation, consisting of corn, corn, and wheat without winter cover crop, was in common use. Many farmers adjacent to the tidal rivers used "green fish" as a fertilizer, but the quantity was limited and means of transformation inadequate so the practice was not general. It was customary to cultivate rather large acreages, but with a very small acre yield.

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[1] Paper read as a part of the symposium on "Crop Rotation" at the meeting of the Society held in Washington, D. C., November 19, 1926.

[2] Director, Virginia Truck Experiment Station, Norfolk, Va.

This rotation would be repeated several times or until the production fell to an unsatisfactory point, which was about 5 bushels of corn per acre. The field would then be abandoned. In a short while it would go back into pine forest and remain in that condition for 20 to 40 years, when it would be reclaimed and the rotation started again. It was found that this rest period very greatly increased the productivity of the soil, but that even 40 years was not sufficient to bring the soil back to its original productivity.

As a result of these methods of cultivation, many of the eastern Virginia counties were unable to maintain their populations permanently and many of them were fast losing their inhabitants as early as the beginning of the nineteenth century. As a matter of fact, the 1920 census shows a number of eastern Virginia counties with a smaller population than they were reputed to have had a century and a half earlier. Ruffin makes a plea for the rational and liberal use of calcareous or marl manures as a means of restoring crop productivity. He further states that in former times clovers were used in the rotation, and that while this crop could be grown, the productivity was maintained at a relatively high point but that when the land ceased to produce clover or became "clover sick" the productivity rapidly decreased. The point was made that with the liberal use of marl the farmers were again able to produce clover and thereby increase the acreage yields of grains. Figures are produced to bear out this statement. Many farmers of Ruffin's time found it to their economic advantage to migrate to the newer and more productive lands of the Ohio Valley and the Middle West rather than to go through the then relatively slow process of rejuvenating their worn soils.

As long as the one-crop system prevailed in the cotton districts of the South, it was quite difficult to introduce a systematic crop rotation. The late Hugh N. Starnes of Georgia, states in the Encyclopedia of American Agriculture (Vol. 2) that by using a systematic rotation the yields of cotton are very materially increased. He suggests a rotation as follows:

First year, corn with cowpeas sown at the last working, the corn to be harvested and the cowpeas to be worked into the soil and the ground sown to oats in the late fall; the oats to be harvested the following May or June and the land sown to cowpeas, these to be turned in and the land planted to cotton the following spring. At the end of the first rotation the increase in yield of cotton was always marked. On ground that would normally produce half a bail of cotton per acre the yield frequently would be increased 100%. The second series of rotation would make still a greater increase and the soil productivity might then be maintained at a higher point in successive rotations.

The Rothamsted records furnish the most complete available data on cultural experiments extending over long periods of time. Wheat has been grown continuously on plat 3 of the Broadbalk farm since 1844, alternately with fallow on the Hoos field since 1852, and on the Agdel field in rotation with turnip, barley, legumes, and wheat since 1850. Neither manure nor chemical fertilizers were used in this portion of the experiment. The average yield on plat 3 of the Broadbalk farm from 1852 to 1907, inclusive, was 12.7 bushels per acre; on the Hoos farm, 17.4 bushels per acre; and on the Agdel field, 25.5 bushels per acre. Dividing the records into periods of eight years the maximum average yield of 17.4 bushels per acre was obtained from the Broadbalk plat 3 during the interval from 1844 to 1851, inclusive. The next highest average yield of 16.1 bushels was from 1852 to 1859. Subsequent eight-year average yields were 13.5 bushels, 12.4 bushels, 10.5 bushels, 12.8 bushels, 12.1 bushels, and 11.4 bushels. After the first 16 years the yields were uniformly low, varying from 18 bushels in 1894, which was evidently a good "wheat year" as indicated by the yield obtained from the other plats under observation, to low yields of 9.4 and 9.8 bushels, respectively, for the two preceding years, followed by a yield of 10 bushels per acre in 1895.

While the yields from Hoos field were somewhat better, they were unsatisfactory after the first and second periods of eight years each. The average yield from 1852 to 1859 was 30.8 bushels and from 1860 to 1867, 20.2 bushels per acre; but the average yields in the next five successive eight-year periods were 14.3, 11.9, 17.3, 14 4, and 13.9 bushels per acre, respectively. The average yield for the entire 56 years was 17.5 bushels. Here again the yields were uniformly low after the first 16 years of the series.

The wheat on the Agdel field grown in the four-year rotation with turnip, barley, and legumes gave yields of 35.3; 27.5, 21.1, 19.9, 27.5, 26.8, and 20.1 bushels per acre for the respective eight-year periods, or an average of 25.5 bushels per acre for the entire period. These data would seem to indicate that a satisfactory yield could not be maintained on plat 3 of the Broadbalk farm with continuous cropping or by alternating with fallow (Hoos field). The data for these comparisons are presented in Table 1.

These yields are practically twice as high as those obtained without the rotation and 50% higher than those obtained where the wheat

TABLE I.—*Average yields of wheat in bushels per acre for eight-year periods at Rothamsted.*

Period	Broadbalk, plat 3, wheat every year	Hoos, wheat alternate with fallow	Agdel, rotation of turnips, barley, legume, and wheat	Broadbalk, plat 2, wheat every year with farm manure	Broadbalk, plat 8, wheat every year with minerals and 129 pounds nitrogen
1852–59	16.1	30.8	35.3	34.4	36.8
1860–67	13.5	20.2	27.5	35.8	39.7
1868–75	12.4	14.3	21.1	35.3	36.0
1876–83	10.5	11.9	19.9	28.6	32.3
1884–91	12.8	17.3	27.4	39.2	38.2
1892–99	12.1	14.4	26.8	39.8	37.3
1900–07	11.4	13.9	20.1	35.2	39.3
General Average	12.7	17.4	25.5	35.5	37.1

TABLE 2.—*Yields of corn, oats, and wheat in six-year and three-year rotations at the Missouri Experiment Station.*[a]

	Six-year rotation				Three-year rotation			
	Yield per acre		Increase from rotation		Yield per acre		Increase from rotation	
	Continuous cropping	Rotation			Continuous cropping	Rotation		
	Bushels	*Bushels*	*Bushels*	%	*Bushels*	*Bushels*	*Bushels*	%
Corn..	27.8	44.6	16.9	60.4	39.0	51.0	12.0	30.8
Oats...	33.6	34.6	1.0	3.0	—	—	—	—
Wheat.	23.4	30.9	7.5	32.0	20.1	28.3	8.2	40.8

[a] In the six-year rotation the yields are averages of six crops of corn, five of oats, and six of wheat. In the three-year rotation the yields are averages of ten crops of both corn and wheat. Stable manure was used.

was grown alternately with fallow on Hoos field. The average yield on Broadbalk plat 2 over the 56-year period was 35.5 bushels per acre and on plat 8, 37.1 bushels per acre. It should be noted, however, that plat 2 received an annual dressing of stable manure and that plat 8 received chemicals, plus 129 pounds of nitrogen. Thus it will be seen that by the use of either stable manure or chemicals the average yield of wheat was almost three times as great, even though continuous cropping was practiced.

The rotation experiments of the University of Missouri were begun in 1888. The soil on which these experiments were conducted is designated as Putnam silt loam. It is described as a dark brownish layer 4 to 6 inches thick. Below this there is another gradation into a brown, heavy clay loam, rather impervious in character. At depths from 13 to 18 inches the soil is a yellowish gray, silty clay loam, more friable than the layer above it. The soil field is fairly uniform.

The two rotations considered are the six-year rotation, consisting of corn, oats, wheat, clover, timothy and timothy, and the three-year rotation of corn, wheat, and clover.

The yields (Table 2) of the six-year rotation are based on an average of six crops of corn, five of oats, and six of wheat, and those for the three-year rotation on an average of ten crops of both corn and wheat. The mean application of manure was 6.8 tons annually in both rotation and continuous culture. In the six-year rotation the yield of corn was increased 60.4%, that of oats 3%, and that of wheat 32%, while in the three-year rotation the yield of corn was increased 30.8% and that of wheat 40.8%, over the yields of the corresponding continuous cropping plats.

The results obtained from the Ohio experiments (Table 3) are somewhat similar. In this case the corn and oats were fertilized with 160 pounds of nitrate of soda, 160 pounds of acid phosphate, and 100 pounds of muriate of potash, while the wheat was fertilized with 120 pounds of nitrate of soda, 50 pounds of blood, 160 pounds of acid phosphate, and 100 pounds of muriate of potash.

TABLE 3.—*Yields of corn, oats, and wheat in bushels per acre in rotation at the Ohio Experiment Station.*

	Continuous culture	Rotation	Increase	
			Bushels	%
Corn	35.88	46.60	10.72	29.9
Oats	39.17	51.24	12.07	30.8
Wheat	19.74	28.12	8.38	42.5

It will be seen that by means of the rotation the yields of corn were increased 29.9%, those of oats 30.8%, and those of wheat 42.5%.

Incidentally it should be noted that the Ohio soils seem to give very good results on long-time cultivation without the addition of any organic matter, except the crop residues.

The Delaware Experiment Station has recently shown (Table 4) that marked increases in the yield of corn were obtained in a rotation of (1) corn and cover crop of rye and vetch, (2) soybeans, (3) wheat, and (4) clover and timothy over yields secured when corn was grown continuously. The average yield from plats on which corn was grown annually and followed with a cover crop of rye and vetch and on which no fertilizers were used was 16.7 bushels of grain and 1,815 pounds of fodder per acre annually from 1908 to 1923, but the yields of corn grown in a four-year rotation were 42 9 bushels of grain and 3,603 pounds of fodder.

TABLE 4.—*Yields of corn grown continuously and in rotation at the Delaware Experiment Station.*

Soil treatment	Continuous cultivation		Rotation		Increase			
	Grain in bushels per acre	Fodder in pounds per acre	Grain in bushels per acre	Fodder in pounds per acre	Grain *Bushels*	%	Fodder *Pounds*	%
None .	16.7	1,815	42.9	3,603	26.2	156.9	1,788	98.5
Nitrogen, phosphorus, and potassium.. .	57.8	3,470	76.5	5,630	18 7	24.4	2,160	62.2

On similar plats on which 125 pounds of nitrate of soda, 250 pounds of acid phosphate, and 75 pounds of muriate of potash were applied annually, the continuous cropping system gave a yield of 57.8 bushels of grain and 3,470 pounds of fodder and the corresponding rotation yields were 76.5 bushels of grain and 5,630 pounds of fodder per acre. Without the chemicals the rotation gave an increase of 26.2 bushels of grain and 1,788 pounds of fodder per acre, and with the chemicals the corresponding increases were 18.7 bushels and 2,160 pounds of fodder.

It is worthy of note that on the continuous cropping plats without the use of chemicals only 28.6% of the corn was classed as sound, but on the similar rotation plat 60.8% was sound. On similar plats on which the chemicals were used the continuous cropping gave 78.3% sound corn and the corresponding rotation plat gave 89.1% sound grain.

The results of this work indicate that rotation alone was not sufficient to maintain a high yield on the type of soil used in these tests. By the addition of nitrogen, phosphorus, and potassium the grain and fodder yields on the continuous cropping plats were increased 246.1% and 91.2%, respectively, and on the rotation plats 78.3% and 55.9%, respectively.

The value of cover crops in rotation as a means of increasing yields of certain truck crops is apparent from the results obtained on the plats of the Virginia Truck Experiment Station. A rotation was arranged on a certain field to include two crops of kale, three of cabbage, three of potatoes, three of sweet potatoes, and one of German millet. These 12 crops were grown during the nine-year period from 1912 to 1921. For possibly 20 years prior to 1908 the field had been permitted to grow in weeds which were usually burned off. From 1908 to 1912 it was under cultivation in potatoes and other truck crops and very little organic matter was added in the form of manure or crop residues except the roots of the cultivated plants left after harvesting.

The field was divided into two equal parts. In one part a cover crop was grown and turned under once each year during the interval between the truck crops and on the other part the ground was allowed to remain fallow while the cover crops were grown. Both parts of the field received an annual application of the same amount of nitrogen, phosphorus, and potassium. The average acre yields obtained are shown in Table 5.

TABLE 5.—*Average yield of truck crops grown in rotation at the Virginia Truck Experiment Station.*

Crop	Rotation with fallow between truck crops	Rotation with cover crop between truck crops	Increase by use of cover crop	
	Pounds	*Pounds*	*Pounds*	%
Kale, 2 crops ..	11,880	13,360	1,480	12.5
Cabbage, 3 crops	9,480	12,080	2,600	27.4
Potatoes, 3 crops	9,240	13,860	4,620	50.0
Sweet potatoes, 3 crops....	15,840	14,220	—1,620	—10.3
Millet, 1 crop. .	6,000	9,600	3,600	62.5

It will be seen that by the use of cover crops the yields of kale were increased 12.5%, those of cabbage 27 4%, those of potatoes 50%, and those of millet 62.5%. The yields of sweet potatoes, however, were decreased 10.3%. While no attempt was made to determine the amount of organic matter turned under during the period of this rotation, the cover crops made a very good growt h,consequently a large amount of material must have been used. It is generally believed that sweet potatoes make their largest yields when the ground is well supplied with mineral plant foods but does not contain too much organic matter. In this case the sweet potato vines on the cover crop portion of the field made an excessivly large growth, but the tuber yield was relatively smaller.

Early potatoes were planted on another field in March and harvested in June. One portion of the land was immediately planted to corn in 5½-foot rows and rye sown at the last working. The ears of the corn were harvested in the fall and the stalks with the rye were turned under the next spring and the rotation repeated. On the other portion of the field Early Orange Sorghum was sown broadcast at the rate of 1½ bushels of seed per acre immediately after the potatoes were harvested. The sorghum was disked into the ground in October and rye sown immediately. This was turned under the following spring and the rotation repeated.

On the portion of the field on which the potato, corn, and rye rotation was followed the average annual acre yield of potatoes for the two complete rotations was 151.5 bushels and the average corn yield 35 bushels. The yield of corn was probably curtailed by reason of the excessive wide rows and the late planting incident to harvesting potatoes in June. The portion of the field on which the potato, sorghum, and rye rotation was followed gave an average annual acre yield of 214.5 bushels, which was 63 bushels, or 41%, in excess of that obtained from the potato, corn, and rye rotation.

The nine-year truck crop rotation was conducted on the Norfolk loam type of soil, while the other rotation was conducted on the Sassafras sandy loam. It will thus be seen that on both the Norfolk loam and the Sassafras sandy loam types of soil the turning under of cover crops in the rotation has materially increased the yields. It is obvious that the potato, sorghum, and rye rotation omitted the corn, thus sacrificing the 35-bushel yield of grain. But in lieu thereof an increase of 63 bushels of potatoes was obtained.

The control of diseases affecting crops is no small factor in truck crop rotation. Experience has shown that such diseases as Fusarium wilt and Septorial blight of tomatoes and Fusarium wilts and black rot on sweet potatoes may be largely controlled by practicing a wide rotation that will not bring these particular plants back on the same land more than once in four or five years.

There are certain diseases that are transmitted from one crop to another, such as Rhizoctonia in potatoes which frequently occurs on beans if they are grown in the late summer immediately after early potatoes. By following potatoes with corn or some other non-susceptible crop, the injury from this source may be held in check. It is well known that black rot and Fusarium of cabbage may be transmitted to kale, collards, cauliflower, and brussel sprouts. Truck farmers have long since learned that these crops should not follow each other in close sequence.

The Rhode Island Experiment Station has shown conclusively that the sequence of crops has a marked influence on the yields obtained in many systems of rotation. This is especially noticeable with such plants as are commonly grown by market garden and truck farmers.

The truck crop farmers in eastern Virginia who practice a rather intensive system of cropping have developed certain rotations that are worthy of note. The most popular of these at the present time in Northampton and Accomac Counties, where potatoes are the main crop, is a three-year rotation, consisting of potatoes, corn, and rye both the first and second years, and sweet potatoes and rye the third year. The potatoes are planted in February or March and corn is planted between the rows at the last working. Rye is sown broadcast in the corn about the middle of August. The grain is harvested from the stalks while they are still standing in the field. The corn, fodder and rye are turned under in January or February preparatory to the succeeding potato crop. From 1,600 to 2,000 pounds of commercial fertilizers carrying 7% ammonia, 6% phosphoric acid, and 5% potash are used with each of the potato crops and from 800 to 1,000 pounds of commercial fertilizers carrying 4% ammonia, 6% phosphoric acid, and 8% potash are used with the sweet potatoes.

This system of rotation and soil management has been in practice for the past 20 or 25 year, and has maintained a relatively high acre yield. It is worthy of note that the average corn yield is approximately 35 bushels per acre. It should be remembered, however, that the corn is planted relatively late in the season, after the potatoes are well matured and in rows approximately 66 inches apart.

In the more intensive trucking region in Norfolk County, Virginia, early potatoes are grown as a spring crop. These are followed by a cover crop, consisting of native grass which may be cut for hay, or a legume, such as soybeans or cowpeas, which may be grown to turn under in the early fall. Cabbage is planted in November and harvested the following April and May, and corn is planted after the cabbage. Soybeans are sometimes planted in the rows with the corn and rye is sown between the rows at the last working of the corn, and potatoes are planted again the following year. This rotation consists of two main crops, potatoes and cabbage, and two so-called catch crops, such as a hay crop and a corn crop. This rotation has proved very satisfactory, but it does best when supplemented with applications of 8 or 10 tons of stable manure every three or four years. There are many modifications of this rotation, in which the more intensive truck crops, such as spinach, kale, beans, peas, beets, and cucumbers are grown. In all of these, however, provision is made for turning under at least one crop of organic matter per year. Experience has shown that it is impractical to grow truck crops on the coastal plain soils of the middle south without turning under liberal quantities of cover crops or stable manure. In this connection it should be remembered that the climatic conditions are such that the soil flora is active practically the entire 12 months of the year.

2. SOME PRINCIPLES INVOLVED IN CROP SEQUENCE[1]

FIRMAN E. BEAR[2]

It is a well-known fact that the acre yields of most crops can be maintained at a higher level with greater economy in the use of manure and fertilizer if the crops are grown in rotation rather than in continuous culture. Weir's (15)[3] recent contribution on this subject indicates that, on the average, rotation is 75% as efficient as fertilizers in maintaining and increasing crop yields. But the effectiveness of a rotation depends upon the nature of the crops that enter into it. Thus the common rotation of a cultivated crop, a small grain, and a legume hay crop indicates recognition of the need of taking advantage of the differences in the characteristics of crops as related to their effects, or the effects of the special treatments they receive, on the soil and thus indirectly on each other.

Considerations of economy usually force the adoption of the principle of rotation and determine, in large part, the crops that enter into it. Furthermore, they usually determine the sequence of the crops in the rotation. However, since it is known that crops do affect the yields of the crops that follow after them, it seems desirable to know what is responsible for these effects and the extent to which it may be worth while to give thought to this problem in the choice and sequence of the crop to be grown.

Of the various theories that have been suggested in explanation of these frequently observed effects of crops on their successors, the following have received more or less serious consideration.

1. Theory of toxic excretions from the roots of plants.
2. Theory of differences in the kinds and quantities of nutrients required by plants.

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[1] Paper read as a part of the symposium on "Crop Rotation" at the meeting of the Society held in Washington, D. C., November 19, 1926. Contribution from the Department of Soils, the Ohio State University, Columbus, Ohio.

[2] Professor of Soils.

[3] Reference by number is to "Literature Cited," p. 533.

3. Theory of differences in composition and habits of growth of plants in relation to the control of diseases and insects.

4. Theory of the differences in the nature of the waste products and residues of plants in relation to the micro-biological population of the soil and its activities.

5. Theory of differences in the feeding powers of plants for nutrients in the soil solution.

6. Theory of differences in the effects of plants on the soil reaction and indirectly on its content of toxic ions.

Some of these theories are of sufficient age to have passed through recurring cycles of favor and disfavor. The more recent of them have not yet been given the test of time.

According to Clements (5), who has reviewed the rather extensive literature on the first of these theories, there is little evidence that plants excrete any substances that might be toxic to other plants except carbon dioxide. This normally diffuses into the atmosphere and would have no ill effects except perhaps in poorly drained soils where, under anaerobic conditions, reduction compounds might be produced as a result of the decomposition of soil organic matter that would be toxic to succeeding crops.

The second theory, discussed by Liebig (13) but proposed at some earlier date, suggests the growing of crops in sequence which vary in their nutrient requirements but in a somewhat complementary manner. Thus, clover precedes corn because of the capacity of the former to accumulate nitrogen and the need of the latter for large amounts of this element. To this extent, at least, the principle suggested by Liebig can be applied. Legume crops are grown preceding crops that require large amounts of nitrogen, if the soil is deficient in this element.

The tobacco crop (7) is of especial interest in this connection, since, although it responds remarkably to the good effects of a preceding clover crop or to manure, with some types of this crop the quality is lowered by the presence of large amounts of available nitrogen. Thus, Green (8) suggests a rotation of tobacco, wheat, grass (two years), corn, cowpeas, and red clover for sun-cured tobacco, while Cocke (6) adopts the same rotation for bright tobacco except that the red clover is eliminated. In the latter case, clover increases the yield but lowers the quality. Similarly, the dark tobaccos of Ohio and Wisconsin are grown on heavily manured clover sods, while bluegrass sods are turned under for the best quality of Burley tobacco. Connecticut tobacco is grown continuously and with cottonseed meal as the source of most of the nitrogen. This is for the purpose of securing an extra fine quality of leaf, but also for controlling the disease known as the brown root-rot which flourishes under the rotation system of cropping (12).

Reference to Cocke's suggested rotation shows that he has chosen cowpeas rather than clover to precede the bright tobacco. It is evident that the mere fact that a crop is a legume does not justify the conclusion that it yields up large amounts of nitrogen to the succeeding crop. Alfalfa sods are not held in as high esteem as are those of red clover and sweet clover. Ohio data (1) indicate that wheat yields following potatoes, red clover, oats, corn, and soybeans are in the order in which the crops are named, the lowest yields following soybeans. Determinations of the nitrate contents of the soils at intervals during the months of September, October, and November gave results which indicate that the explanation is to be found in the differences in the amounts of available nitrogen in the soil following the various crops. In so far as nitrogen is concerned, there seems no exception to the general statement of principle that the crops whose residues yield up the largest amounts of nitrogen should be grown preceding the non-legume crops whose nitrogen requirements are the highest, if nitrogen is the element normally in deficiency in the soil in question. Sweet clover, red clover, tobacco, potato, and sugar beet residues meet these requirements. Soybeans, cowpeas, timothy, bluegrass, wheat, and oats are a few of the crops whose residues do not yield up their nitrogen so readily.

The lack of availability of the nitrogen in the residues of the last named group of crops is commonly explained on the basis of the wide carbon-nitrogen ratio of these materials and on the assumption implied in theory No. 4 listed above. Whiting's (16) review of the evidence on this point indicates that there are three general classes of plant residues that yield up considerable amounts of nitrogen for immediate use, *viz.*, fresh green materials, the whole plants of all legumes, and all fresh crop residues that contain relatively high percentages of nitrogen.

There would seem to be equally as valid reasons for postulating a carbon-phosphorus ratio to explain the bad effects of highly carbonaceous materials in the soil on the yields of crops as to assume that they are due to the using up of the available nitrogen. The carbon-phosphorus ratio is particularly significant by reason of the relatively high phosphorus content of bacterial cells and the fact that phosphate fertilizers are especially effective on most soils. There is a fairly constant nitrogen-phosphorus ratio in soils which has been shown by Bear and Salter (3) to be about 2.7 for Dekalb silt loams.

Investigation of other soils reveals that this ratio is normally between 2 and 3. A phosphorus deficiency limits nitrogen fixation and nitrogen accumulation. It seems probable that if the crop residues of a previous crop have a high carbon-phosphorus ratio and if the crop which follows has an especially high phosphorus requirement, the yield is quite likely to be below normal unless supplemental phosphate has been applied. In this connection it may be well to note that clover residues are relatively high in phosphorus as well as in nitrogen and that the ADCO chemicals, for use in the production of artificial manure, carry both of these elements.

The theory of the differences in the mineral requirements of plants is discussed at considerable length by Liebig who states it as follows, "When we grow in the same soil for several years in succession different plants, the first of which leaves behind that which the second and the second that which the third may require, the soil will be a fruitful one for all the three kinds of produce."

Hartwell and Damon (10), in the first report from the Rhode Island Experiment Station on the subject of crop sequence, show that the yields of onions are lowest following cabbages, mangels, rutabagas, and buckwheat and highest after squash, timothy, alsike clover, and red top. In preceding buckwheat, the order is practically reversed as to the effects on the yields. They suggest that the effects are less pronounced on limed soil. In a subsequent publication (11) two significant comments are made, *viz.*, that the smallest yield does not necessarily occur after the growing of a crop which removes the largest amounts of the most needed nutrient; and that the best yield of a base-loving crop, when grown on an acid soil, follows the crop which gives rise to the least acidity in the soil. One might suspect that, if the harmful acidity had been eliminated by liming, then the smallest yield would follow the crop which removes the largest amount of the most needed nutrient or, as is the case with nitrogen after timothy and bluegrass and is probably also true of phosphorus after these and similar crops, at least most effectively reduces the quantity that is available for the following crop.

It is evident that if a non-legume plant has a high requirement for base-forming elements as compared to its need for the acid-forming elements, particularly nitrogen, its growth will tend to increase the acidity of the soil. Conversely, if it has a relatively high nitrogen requirement its growth will tend to reduce the acidity of the soil. To grow a non-legume crop and plow it under should not affect the reaction of the soil. But to grow a legume crop and plow it under should increase the acidity of the soil. If only the residues of crops are considered, there may be very little difference in the effects of those from legumes and those from non-legumes on the soil reaction, but, in general, the higher their content of nitrogen the more objectionable they might be, if the soil was acid and if acid soil conditions were not conducive to the production of optimum yields of the crop that was chosen to follow. It is of interest to note that if the bases and acids of wheat straw are calculated to their respective calcium carbonate equivalents, the result is a considerable excess of base over acid, if silica is omitted from the calculation.

Plants which grow well on acid soils and which are yet able to secure considerable amounts of the base-forming elements are quite likely to make the soil more acid than it was before they were grown. This may be true even though such plants require large amounts of nitrogen since they may have secured a considerable part of this in the form of ammonia or of amino acids. Burgess (4) has shown that mangels increase the acidity and also the content of active aluminum in soils, while red top has the opposite effect. This is the apparent explanation of the better crop of onions after red top than after mangels, since onions are very sensitive to acid soil conditions. Burgess' data would also indicate a reduction in the available phosphorus to correspond somewhat with the increase in acidity of the soil. This is the probable explanation of the lower yields of oats and corn following mangels, since neither of these crops are very sensitive to acid soils but require considerable amounts of available phosphorus.

There seems also to be some relationship between increased acidity and the content of available potassium in the soil. Onions and corn contained more potassium following mangels than after crops which did not alter the soil reaction to such an extent.

It is necessary to keep in mind that crops differ in their foraging powers for elements in the soil as well as in their sensitiveness to soil acidity. Every agronomist has noted the ability of certain crops to produce satisfactory yields when grown on soils that are very unproductive of other crops. Rye, buckwheat, millet, navy beans, carrots, and sweet clover are notable examples of poor-land crops. Corn, barley, bluegrass, peas, beets, and alfalfa are equally noteworthy as requiring good land.

Truog (14) comments on evidence which indicates that sweet clover and alfalfa can utilize the potassium of orthoclase and thus produce normal growth at lower concentrations of this element than can corn and buckwheat. On the other hand, buckwheat and corn grow well on quite acid soils. This indicates that they can secure adequate amounts of calcium and other needed basic elements from the soil at relatively low concentrations of these elements. Bauer's (2) work indicates that sweet clover, red top, buckwheat, rye, and alfalfa can utilize the phosphorus of phosphate rock better than can red clover, wheat, oats, corn, and timothy.

One might hypothecate two cases with reference to low response of plants to the use of liming materials and fertilizer elements on soils that are deficient in them as follows:

1. Low response indicates ability of the plant to utilize low concentrations of the element supplied.

2. Low reponse indicates relatively small need for the element supplied.

If the former is true, then according to the work of Hartwell (9) and his associates, rye should not precede barley if nitrogen is deficient; carrots should not precede turnips if phosphorus is deficient; corn should not precede beets if potassium is deficient; and potatoes should not precede onions if lime is deficient, etc. If the latter is correct, then rye could well precede barley, carrots could precede turnips, etc. The experimental evidence favors the first of these hypotheses in all of the cases mentioned.

Similarly two cases could be hypothecated with reference to high response of plants to liming and fertilizer materials when used on soils that are deficient in them as follows:

1. High response indicates little ability of the plant to utilize solutions of low concentration of the element supplied.

2. High response indicates large need for the element supplied.

In either case and again following Hartwell's classification of crops as to fertilizer response, a plant which has a high response should not follow another having a high response. Beets should not precede onions if the soil is acid; buckwheat should not precede barley if nitrogen is deficient; cabbage should not precede turnips if phosphorus is deficient; and squash should not precede cucumbers if potassium is deficient, etc.

Probably the most important crop in many ways in the general farming rotation is the legume. In the long run the rotation which gives this crop the advantage in the choice of position in the crop sequence is the one which is likely to yield the highest returns. This is on the assumption that lack of available nitrogen is a limiting factor in crop growth. It also assumes that the mineral and reaction requirements of the legume and its nodule bacteria have been met so that they can exercise their well-known functions of accumulating atmospheric nitrogen. This usually limits the clover to one of two positions in general farming rotations, *viz.*, either following oats or wheat. If there is a general statement that may be applied to the choice as between these two crops as nurse crops for clover, it is that clover follows oats better in southern latitudes than it does farther north. In other words, the more unfavorable the climatic conditions are for oats, the better the chance of getting a stand of clover when it is seeded in the oats.

A principle of crop sequence that merits some attention, and which might be considered as a modification of the principle defended by Liebig, is that of growing crops in the descending order of their lime-requirements. If the soil is limed very heavily for alfalfa, the sequence to follow might then be alfalfa, sugarbeets, barley; red clover, tobacco, wheat; alsike clover, corn, oats; and soybeans, potatoes, rye. This is in effect the principle of crop sequence that is followed in parts of northern France and in Belgium where alfalfa appears in the rotation every eleventh or twelfth year and heavy applications of lime are made in preparation for this crop.

It seems probable that the well-known good effects of partial sterilization of soils and certain other additional benefits might be realized in market gardening by the alternate use of sulfur and burned lime and the growing of a sequence of crops to correspond. Thus the soil could be treated with sulfur preceding the growing of a crop like potatoes and then limed very heavily for a high lime-requirement crop, such as cabbage, which might then be followed by a series of crops in the descending order of their need for lime.

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3. LEGUMES AND GRASSES IN CROP ROTATION[1]

T. L. Lyon[2]

In 1919, Pieters (20)[3] published a very exhaustive review of the experimental work in this country with green manures. He discussed clovers, alfalfa, and, to some extent, grasses in his review, as well as the annual green manure crops. The present paper concerns itself only with those investigations reported since Pieters' paper appeared. Those matters on which he has arrived at positive conclusions are not here debated, but questions which he considered still open are discussed in the light of more recent research.

A very considerable literature on the subjects included in this paper has accumulated since Pieters' review was written. It results from experiments that were more carefully conducted than many of those instituted during the earlier years of the work. One can, therefore, proceed with more confidence in drawing conclusions.

ROTATIONS IN WHICH THE HAY CROP IS EITHER GRASS, CLOVER, OR ALFALFA

As a rule clover has proved to be a better crop than grass in its effect on the yield of at least the first crop following the hay. There are, however, some exceptions that cannot be ignored. Pieters, in his summary, says, "The results at the Rhode Island Station point at least to the possibility that under some conditions the roots of a grass sod may be quite as efficient as a legume. Some of the Michigan and Minnesota work might be interpreted in the same way, though there is little evidence to this effect at present. At the Maryland Station better yields were produced after rye than after crimson clover."

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[1] Paper read as a part of the symposium on "Crop Rotation" at the meeting of the Society held in Washington, D. C., November 19, 1926.

[2] Professor of Soil Technology, Cornell University, Ithaca, N. Y.

[3] Reference by number is to "Literature Cited," p. 544.

While it is hardly necessary to mention the very numerous cases in which clover or alfalfa was more beneficial than grass, the exceptions may well be noted.

At the New York State Station (Geneva) two rotations were conducted (9). Both consisted of corn, oats, wheat, and hay. In one rotation the hay crop was timothy and in the other red clover. Each rotation was subjected to four different fertilizer treatments, *viz.*, (a) farm manure, (b) complete commercial fertilizer, (c) partial fertilizer, and (d) no fertilizer. In all of these, except the rotations receiving no fertilizer, the average yield of cereal crops for the period 1897–1913 was greater from the rotation containing red clover. In the rotations having no fertilizer the yields of cereal crops were less from the clover rotation.

Mooers (16) reports a one-year test at Knoxville in which sod of tall oat grass plowed under gave as large yields of wheat as did sod of red or alsike clover.

At the Ohio Station three-year rotations of corn, wheat, and hay have been conducted for nine years. In one rotation the hay crop was timothy, in another red clover, in another sweet clover, and in another alfalfa. The average yields of corn were less in the red clover rotation than in the timothy, but were larger in the other two rotations. The following wheat crop, however, averaged larger in the red clover rotation than in the timothy rotation.

In an experiment at the same station in which corn, oats, wheat, and hay were grown, the hay crops were in one case red clover and in the other timothy. Here again corn produced less following red clover, but the oat and wheat crops averaged larger than in the timothy rotation. These two experiments were on Canfield silt loam. Corn received 6 or 8 tons of farm manure and the cereals were fertilized with acid phosphate. Each crop of the rotations was represented every year, hence the plats were replicated three and four times. It will be noticed that the advantage which usually comes from the use of red clover did not appear until the second year after the sod was plowed under. It would be interesting to know how the nitrate nitrogen content of the soil in the two rotations compared during the year following the hay. A possible reason for the very unusual result will be suggested later. The experiments, cited above, at the New York State Station and at the Tennessee Station do not require further consideration for the reasons that the former result is not significant when the yields are tested by the method of Student and the latter was conducted for one year only. The figures from the Ohio Station have not been published, but were kindly furnished by Dr. Salter.

At the Dickinson and Hettinger Substations in South Dakota (17) a rotation of brome grass, oats, corn, and wheat produced larger yields of all three cereals than did a rotation in which red clover or sweet clover took the place of brome grass. At Dickinson a rotation containing alfalfa instead of brome grass yielded less of the three cereals than did the one with brome grass, but at Hettinger the alfalfa rotation was superior.

The stands of clover were unsatisfactory throughout the duration of the experiment, but brome grass did not always make a successful catch and slender wheat grass was occasionally substituted. Alfalfa was on the land for three years instead of two as was the case with the grass and clover, but a catch of alfalfa was sometimes not obtained until the second year.

Another experiment in Montana (2) was conducted at Judith Basin from 1909 to 1915, inclusive, under dry farming conditions. Brome grass, alfalfa, and red clover were each grown for two years on different plats and these were followed by corn, oats, and wheat. The corn crops failed in all three rotations The other indicator crops were somewhat better, on the whole, in the alfalfa and clover rotations.

At the Edgeley Substation in North Dakota (24) wheat, oats, and barley after corn gave higher average yields over a period of 14 years than they did when grasses or small cereals were substituted for the corn.

Apparently the determining factor in crop production over much of the trans-Missouri region is usually moisture, although this would not apply to exceptional years of large rainfall. The crop or tillage that leaves the most moisture in the soil is likely to be the one that is followed by the largest crops.

In this connection it may be stated that while sod has usually not been so beneficial in causing large yields of succeeding crops as has fallow or an intertilled crop under dry farming conditions, yet in similar regions the results are reversed when the soil is irrigated.

At Scott's Bluff, Nebraska, Huntly, Montana (21), and Umatilla, Oregon (6), alfalfa sod plowed under increased the yields of such crops as corn, potatoes, oats, and sugar beets as compared with the effect of non-legumes. On the other hand, at Belle Fourche, South Dakota (21), on a heavy clay loam rich in organic matter there was no beneficial effect on potatoes, a doubtful effect on oats, except yield of straw, and also a doubtful effect on sugar beets.

IS THE BENEFICIAL EFFECT OF RED CLOVER DUE TO ITS PROPERTIES AS A LEGUME?

Pieters has remarked, "As a rotation crop, clover has been shown to be beneficial, but there is need for more exact work to show, if possible, how much of this benefit is due to the clover as a legume and how much must be ascribed to the growing of crops in a rotation." A fair test of this question would be to compare the yields of similar crops grown in the same years in two or more rotations in which clover is replaced by some other crop grown in the same year as the clover. The crop substituted for clover should not be the same as the one preceding or the one following it in the rotation. Since Pieters reviewed the subject there have been a number of such experiments.

On the Worthington experiment field in Indiana (26) the relative value of red clover and timothy was tested by a three-year rotation consisting of wheat, corn, and hay. The latter crop was provided by clover in one case and timothy in the other. The average yields for the period 1914-1918 resulted in 2.1 bushels more corn and 6.1 bushels more wheat per acre annually from the clover rotation. At the North Vernon field the clover rotation furnished 3.2 bushels more corn and 4.4 bushels more wheat per acre each year.

At the Westport field, Indiana, in a similar rotation, 5.2 bushels more corn and 5.4 bushels more wheat were obtained from the clover rotation. At the Francisco field corn yielded 9.7 bushels more and wheat 6.7 bushels more in the clover rotation. In these experiments the soil was limed and the wheat received phosphorus and potassium.

At the Ontario Station (27) an experiment was conducted for three years to determine the relative influence of timothy and alfalfa sod on the yields of succeeding corn and wheat crops. New stands of timothy sod and alfalfa sod were plowed under each year and planted to corn which was followed by wheat. The yield of corn was 6.1 bushels per acre more after alfalfa than after timothy and the yield of wheat was 19.4 bushels more.

The effect of red clover on the yield of wheat as compared with corn or oats when they were substituted for clover in a two-year rotation has been tested at the Ohio Experiment Station (1). The average yield per acre of seven wheat crops was 31.45 bushels after corn, 34.69 bushels after oats, and 34.98 bushels after clover. After potatoes wheat yielded more than after clover, but this has been shown to be due to the very high nitrate content of soil in autumn following the digging of potatoes (25). The very thorough aeration of the soil during the process of digging the potatoes resulted in a high content of nitrate nitrogen which was very beneficial to the late planted wheat.

In a succesion of crops at the Cornell University Experiment Station (10), consisting of oats, wheat, and fodder corn, red clover preceded wheat on certain plats, on others timothy preceded wheat, and on others rye came before the wheat crop. The oat crop was twice as large following clover as after timothy, and following rye it was much less than when preceded by clover. The soil was liberally fertilized with phosphorus and potassium.

At the Virginia Experiment Station (8) corn was grown continuously for seven years, but on one plat crimson clover was seeded at the last working of the corn and on the other rye was seeded at the same time. The next spring the clover and rye were cut for hay and the stubble plowed under for planting corn. Through a period of seven years corn following clover averaged 35 bushels per acre and following rye 17 bushels.

One reason why clover benefits the succeeding crops is apparent when one examines the nitrate nitrogen content of soil in which clover residues have been incorporated. At the Cornell University Experiment Station (12) timothy was grown in large cans in the greenhouse and red clover in other similar cans. The cans were so arranged that the soil could be leached. After the timothy and clover were harvested, the stubble and coarse roots were removed, the soil stirred to a depth of 2 inches, and left thus standing fallow for a month when it was leached. The soil on which clover had grown yielded to the leachings six times as much nitrate nitrogen as did the timothy soil.

That this greater accumulation of nitrates is not always due to a greater growth of clover roots than of timothy roots was demonstrated by another experiment (11) in which timothy roots and red clover roots were analyzed for nitrogen and a quantity of each sufficient to furnish equal quantities of nitrogen were incorporated in soil and allowed to incubate for a few weeks during which period the soil was leached from time to time. The nitrate nitrogen in the leachings from the clover soil was four times as large in amount as that from the timothy soil.

The greater accumulation of nitric nitrogen in the clover soil during the first few weeks is presumably due to the smaller quantity of material it contains which furnishes energy for soil micro-organisms and enables them to utilize nitrate nitrogen for their own growth, thus removing nitrogen from the nitrate form and decreasing its availability.

These experiments with the cans indicate that during the first few weeks clover furnishes more nitrate nitrogen than does timothy. They do not, however, tell the whole story. At a certain stage in the decomposition of timothy sod it may produce more nitric nitrogen than does clover sod which has been incorporated with soil for the same length of time.

This has been shown by a continuation of the last experiment with the cans which demonstrated that, although the quantity of nitrates leached from the clover soil was four times as large as from the timothy soil at the end of the first month, it was found two months later that more nitrates were being accumulated in the timothy soil than in the clover soil. The slow development of nitrate accumulation in timothy soil is better suited to supplying the corn crop, which absorbs its nitrogen through a long period, than a small cereal crop which requires its nitrogen early in the season.

Legumes are more likely to increase the content of nitrate nitrogen than total nitrogen in soil. At least the former property is more pronounced than the latter. For that reason the effect of a legume on crop yield is more likely to be exerted on the first crop that follows it than on later ones. In the Ohio experiment previously cited the first crop following clover was not so favorably influenced as were the second and third. It seems probable that the stable manure interfered with the accumulation of nitrates by furnishing energy material for the soil organisms and that they utilized the nitrates and thus prevented the corn from being nourished by the nitrogen which would otherwise have been available.

While red clover has been the legume considered in this discussion, both alfalfa and sweet clover are as effective, or possibly more so, in benefitting the growth of crops that follow them.

GREEN MANURES

Several rather important questions regarding the use of green manures may receive some clarification by bringing together the results of investigations made at a number of experiment stations. One of these is the relative effectiveness of leguminous and non-leguminous plants used for green manuring.

RELATIVE EFFECTIVENESS OF LEGUMES AND NON-LEGUMES FOR GREEN MANURING

In tests conducted at eight experiment stations in humid regions the green manure followed by the largest test crop was in seven instances a legume. The exception was at Woburn, England, where mustard was most effective, rape next, and vetches least. Table 1 contains a list of all of the green manure or cover crops used in the eight experiments and their relative rank in each test.

Of those ranking second in the tests six are legumes and two non-legumes. These two non-legumes are rye and rape. Of those ranking as least effective six are non-legumes and two legumes. These two legumes are soybeans and vetch.

These results would indicate that legumes are, on most soils, more effective as green manures than are non-legumes. It is difficult to say what legume ranks highest or lowest or to make a similar statement for the non-legumes. The soil or climate may favor one kind of plant in one region and another kind in another region. However, it may be said that in the two tests in which red clover was used it stood first and in the three tests in which buckwheat was used it ranked well towards the bottom of the list Vetch did well in the North and cowpeas in the South.

TABLE 1.—*Relative effectiveness of green manures in the production of succeeding crops.*[a]

	(8) Virginia	(15) Delaware	(13) Maryland	(14) Arkansas	(22) Iowa	(19) Woburn	(19) Rothamsted	(5) New York
Soybeans . .	2	2	6	2				
Buckwheat.	4		4					5
Crimson clover .	1		2				2	
Rye	3		6		3			2
Cowpeas. .		1	3	1	2			
Oats . . .		3		4				3
Cowhorn turnip.		4						
Red Clover . .			1		1			
Alsike clover			5					
Velvet beans . .				3				
Vetch.						3	1	1
Rape . .						2	3	
Mustard						1	4	
Field peas.								4

[a]Figures in parenthesis refer to literature citations.

USE OF AN ANNUAL LEGUME TO REPLACE A CEREAL IN A CROP ROTATION

The high feeding value of legumes is generally conceded. In those farming systems in which food for live stock is an important consideration it may be desirable to use an annual legume in place of one of the cereal crops which it has been customary to plant for feed. In some regions it has been found that soybeans will produce more food value than will oats. The question then arises as to what will be the effect of this change in the rotation on the yields of other crops.

At the Kansas Experiment Station (4) a rotation of corn, cowpeas, and wheat was compared with corn, corn, and wheat. The average of seven crops of wheat was 2.3 bushels per acre more for the corn, cowpeas, and wheat rotation.

Rotations consisting of (a) wheat followed by corn, (b) wheat followed by soybeans, and (c) wheat followed by potatoes were maintained for several years at the Ohio Experiment Station (1). Wheat in the soybean rotation yielded an average of 2 5 bushels per acre more than wheat in the corn rotation, but nearly 3 bushels less than wheat in the potato rotation. The advantage that wheat gains from digging the potato crop has already been referred to.

A comparison was made at the Pennsylvania Experiment Station (18) of two rotations, one consisting of corn, oats, wheat, clover, and timothy, and a similar rotation in which soybeans were substituted for oats When the beans were cut for hay, and wheat seeded on the same date on both plats, the wheat after soybeans yielded 2.5 bushels more than after oats When soybeans were allowed to ripen, wheat seeding was delayed too long and the yield was curtailed so that it yielded less than after oats

Another experiment reported from the Ohio Experiment Station (23) does not indicate that soybeans have any advantage over potatoes or oats when used in rotation with wheat and clover, but when substituted for corn the yield of the wheat crop was somewhat greater after soybeans

On the Wilson Farm experiment field in Indiana there are three rotations in which wheat follows soybeans used as a grain crop. In several other rotations wheat follows corn Yields of wheat after soybeans have been compared with yields after corn, there being nine crops of each (26). It is shown that the wheat yields after soybeans amounted to 4.4 bushels per acre more than after corn.

Rotations consisting of soybeans, wheat, and red clover and of corn, wheat, and red clover were conducted on both the North Vernon and the Worthington experiment fields in Indiana (26). These experiments covered the period 1914 18. Yields of wheat at the two places were, respectively, 2.6 and 2.4 bushels per acre larger from the soybean rotation than from the corn rotation.

At the Cornell University Experiment Station (10) oats was replaced by (a) soybeans, (b) oats and peas, and (c) field beans. All were followed by barley which yielded 6.6 bushels per acre more after soybeans than after oats, 0.5 bushels more after oats and peas than after oats alone, and 1.1 bushels more after field beans than after oats.

The rather meager data on this subject indicate a practical advantage to be gained by the succeeding crop from replacing oats and possibly corn by soybeans, especially when clover is not included in the rotation. Since the oat crop is the one which could most easily be spared from rotations in many parts of the country, these data are rather encouraging. The experiments cited do not, of course, involve the question whether the yields of soybeans would warrant their substitution for oats or any other crop, but if any of the prevailing crops are to be so replaced it would probably be the oat crop.

It is rather surprising to find that the yields of wheat following soybeans grown for seed were often more than following corn. The deciding factor in determining whether this substitution shall be made is not the effect on the growth of the following crop but the value of the feed produced.

EFFECT OF ANNUAL LEGUMES PLANTED WITH A CEREAL ON YIELDS OF SUCCEEDING CROPS

It has been found that mixtures of cereals, for instance oats and barley, sometimes produce larger yields of grain than do either of these crops singly. An annual legume has sometimes been planted with a cereal. Mixtures of oats and field peas or oats, barley, and field peas are not infrequently found to give a large yield.

It is in line with the purpose of this paper to consider the effect of such mixtures on the yield of succeeding crops Experiments having a bearing on the subject are few in number, however.

A mixture of corn and soybeans or corn and cowpeas was grown on 25 experiment fields in Missouri (7). A rotation consisting of corn with soybeans or cowpeas, oats, wheat, and red clover was compared with one in which corn was grown alone. The legume was not harvested but was allowed to fall down and was plowed under. The yields of corn were decreased by about 1 bushel per acre by this procedure. The oat crop that followed was increased by 0.6 bushel and wheat the next year was increased by 0.2 bushel per acre. The authors conclude that this mixture is not profitable.

At the Delta Branch Experiment Station (3) in Mississippi soybeans planted in corn increased the yields of cotton grown the following year from 44 to 56%.

At the Cornell University Experiment Station (10) oats and field peas were grown together and followed by a succession of crops consisting of wheat, fodder corn, and wheat. On the other plats oats alone were grown in an otherwise similar succession of crops. When the oat crops succeeded red clover the total yield of grain and roughage following the oats was less from the system in which soybeans were grown, but when preceded by timothy or rye the yields following the oat and soybean mixture were considerably greater than following oats alone. The soil was liberally supplied with phosphorus and potassium fertilizers, but no nitrogen fertilizer was applied.

There have been a number of experiments in which mixtures of soybeans or cowpeas and corn have been grown for silage and a few in which they have been grown for grain. These do not, in the main, give much encouragement to the practice. Consequently there have not been many experiments to determine the effect of these mixtures on the yields of succeeding crops.

The mixture of oats and field peas or of oats, barley, and field peas has proved to be more productive under some conditions than oats alone and the growing of these mixtures appears to aid the crops that follow

GEOGRAPHICAL LIMITATIONS TO USEFULNESS OF GREEN MANURES

Experiments reviewed by Pieters left some doubt as to the effectiveness of legumes, at least annual legumes used for green manure, in the northern Mississippi Valley and in the dry-farming region of the West. The Mississippi Valley has since been shown to offer no exception to the beneficial action of legumes in the soil as instanced by experiments already cited (26, 25, 14, 22) In the dry-farming region, however, their possible effect is often lost for lack of moisture to make them grow or to decompose them in the soil (17, 2, 24). That lack of soil moisture is the explanation would appear from the fact that irrigated soil in the same region gives a good response to legumes (6, 21)

SUMMARY

A partial review of recent experiment station literature concerning experiments to ascertain the effect of legumes, grasses, and green manures on the yields of succeeding crops shows the following.

With a few exceptions experiments in the humid portions of the country have demonstrated the superiority of red clover and alfalfa over timothy in their effect on the yields of crops that follow.

That the beneficial effect of clover is due to its property as a legume has been shown by a number of field experiments in which comparison was made of the yields of similar crops grown in the same years in two or more rotations in which clover is replaced by some non-legume crop grown in the same year as the clover. The same principle has been demonstrated by determining the nitrate nitrogen contained in drainage water from soil in which clover residues have been incorporated and also in which timothy residues have been incorporated.

Tests conducted at eight experiment stations in humid regions indicate on the soils used for the tests a greater effectiveness of legumes as compared with non-legume green manures on the yields of succeeding crops.

The data indicate that a practical advantage is to be gained by the succeeding crop from replacing oats and possibly corn by soybeans, especially when clover is not included in the rotation.

Some tests have resulted in a larger crop following a mixture of corn and soybeans and oats and field peas than after either cereal alone. The total number of trials has been few and results have not been uniform, consequently a definite conclusion cannot be drawn.

The region of dry farming is the only part of this country in which legumes do not affect favorably the yield of the succeeding crop with a reasonable degree of certainty. That lack of soil moisture is the explanation would appear from the fact that irrigated soil in the same region gives a good response to legumes.

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4. CROP ROTATION IN RELATION TO THE AGRICULTURE OF THE CORN BELT[1]

A. T. Wiancko[2]

Through the years that the corn belt has been farmed, it has become quite evident on even the best of soils that continuous corn growing is ruinous to the productivity of the land and that some sort of a scientific rotation of crops must be practiced in order to maintain reasonable crop yields and that the same principles of crop rotation apply on these soils as on other soils in other parts of the country. Wherever continuous corn growing has been practiced for any considerable length of time, yields have invariably gone down and become unprofitable. It has also become evident that short rotations of corn and other grain crops are not satisfactory. There is something else lacking. Other classes of crops must be introduced. This is slowly sinking into the minds of corn belt farmers, but many are not yet convinced and find it hard to change their ways. In the earlier years, the yields of corn were quite satisfactory and continuous corn growing or the short rotation of corn and oats became the rule, particularly on the prairies, and especially among tenant farmers who did not care to raise livestock or by reason of short tenure could not do so and consequently had little or no use for hay crops. Wheat was not a popular crop either, both because of lack of adapted varieties and because oats were more convenient to raise.

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[1] Paper read as a part of the symposium on "Crop Rotation" at the meeting of the Society held in Washington, D. C., November 19, 1926.

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We need only look at what has taken place on the naturally rich prairie soil on the old Morrow plats at the University of Illinois to see what happens without rotation. Table 1 shows the yields of corn in continuous culture in a corn and oats rotation and in a corn, oats, and clover rotation without fertilization of any kind. The experiment was begun in 1876, but yields are not available prior to 1888. Beginning with 1893, the yields are shown when corn appeared in all three of the series. Prior to 1893 corn did not appear on all of the series at the same time.

TABLE 1.—*Yields of corn with and without rotation, Morrow plats, Urbana, Illinois.*[a]

Crop years	Yields of corn in bushels per acre		
	Corn every year	Corn and oats	Corn, oats, and clover
1888	54.3	49.5	——
1892	33.1	——	70.2[b]
1893	21.7	29.6	34.1
1899	50.1	44.4	53.6
1901	23.7	33.7	34.3
1907	29.0	47.8	80.5
1919	24.0	30.5	52.2
1925	19.2	26.7	42.1
Averages of years when corn appeared in all series	27.9	35.4	49.4

[a] Data taken from Ill. Agr. Exp. Sta. Bul. 273. 1926.

[b] After three years in clover which averaged 2.34 tons of hay per acre.

The record of yields clearly shows that continuous corn culture is a losing practice. Rotating corn with oats is somewhat better, but the yields are far short of what they are with a legume in the rotation.

In 1904 these plats were divided into quarters, two of which were continued without treatment and two have since been treated with manure, lime, and phosphate. In Table 2 are shown the yields of corn in the three years since then when corn appeared in all series at the same time.

TABLE 2.—*Yields of corn in continuous culture and in rotation, with and without treatment.*[a]

Crop years	Corn every year		Corn and oats		Corn, oats and clover	
	No treatment	MLP	No treatment	MLP	No treatment	MLP
1907	29.0	48.7	47.8	87.6	80.5	93.6
1913	19.4	32.0	29.2	25.0	33.8	47.8
1919	24.0	43.4	30.5	66.2	52.1	70.8
1925	19.2	45.4	26.7	39.5	42.1	58.7
Averages	22.9	42.4	33.6	54.6	52.1	67.7

[a] Treatment begun in 1904.

While Table 2 shows the yields in only four years because these are the only years in which the yields on all plats are comparable, the results are representative of what is taking place in these experiments. It is clearly shown that even with good soil fertilization continuous corn culture is not satisfactory

At the Missouri Experiment Station there is also an interesting experiment showing the benefits of crop rotation (Table 3).

TABLE 3.—*Experiments in crop rotation, Missouri Station.*[a]

Rotation	Yields of corn in bushels per acre, 1905
Corn, 17 years .	11.8
Corn, wheat, and clover, 17 years	50.7
Corn oats, wheat. clover, and timothy 17 years	54.2
Corn, wheat and clover (manured) 17 years	77 6

[a] Data taken from Mo. Agr. Exp Sta. Cir. 38. 1910.

Granting the need of crop rotation, which has been abundantly proved in many experiments besides those here presented, the problem is to determine what systems of cropping are best adapted to the needs, while at the same time maintaining the soil in a high state of productiveness. The end desired is plain But what must be accomplished along the way and what are the limiting factors that must be overcome?

The great problem in the corn belt, as the writer has observed it through 25 years, is to keep up the organic matter and nitrogen supply of the soil, and the crop rotation or system of cropping has a vital relation to its solution Most farmers do not yet realize the situation and are skeptical and half hearted about applying the remedy. It takes time to change established ideas and practices.

For the most part, the soils of the corn belt were well supplied with organic matter and nitrogen by nature before they were brought under cultivation. Their fertility was wonderful and for a long time they were regarded as inexhaustible, but too much corn growing and constant plowing and cultivating have used up these constituents to the point where they have become serious limiting factors in the fertility of the soil. Both nitrogen and organic matter are more rapidly used up under corn than under small grain or hay. The cultivation given the corn crop hastens the decomposition of soil organic matter and greatly increases nitrification.

A 60-bushel crop of corn, which is only a fair crop, contains about 100 pounds of nitrogen, in grain and stalks, all of which it takes out of the soil. There are also considerable more or less unavoidable, losses of nitrogen during the season that must be taken into account and replaced in some way. The climate of the corn belt is especially favorable to rapid decomposition and nitrification and the frequent stirring of the soil in corn culture greatly accelerates these processes. On the average, through the years of more or less continuous grain growing, mostly corn, much of which has been sold off the land and little or nothing returned, several times as much nitrogen has been removed from the soil each year as has been added in any form. Legume crops have been few and far between, little manure has been produced and much of that has been wasted, and the amount of fertilizer nitrogen used has not averaged a pound to the acre.

Some idea of what has happened and is still going on in corn belt soils may be gathered from a study made by the Indiana Experiment Station in 1913. Analyses were made of 31 samples of cropped soils and 31 samples of virgin soils of the same types from various parts of the state. These analyses showed that on the average the cropped soils during the time they had been farmed had lost 26% of their organic matter, 47% of their humus, and 28% of their nitrogen as compared with the averages of the virgin soils.[3] The loss of these constituents, together with other defects that have been aggravated at the same time, explains why so many of these soils are not producing as good crops as they did in the earlier years of their cultivation. Corn belt farmers have been face to face with this problem of diminishing organic matter and nitrogen supplies in the soil for some time. A few are solving it successfully, but in the great majority of cases conditions are getting worse. The process of depletion is still going on and will continue until there is a general adoption of means that will return to the soil as much organic matter and nitrogen as is removed. To maintain these soil constituents through purchased materials is not economically possible. The needed organic matter is not to be had in that way and nitrogen in commercial fertilizer is too expensive to be economically used to any considerable extent, especially on such low-priced crops as corn and oats. The solution of the problem lies in the production of these materials on the land. This can be done at comparatively little expense through the growth of legumes and here the problem becomes one of crop rotation.

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[3] WIANCKO, A. T. Management of the light-colored clay and silt loam soils. Ind. Agr. Exp. Sta. Cir. 115. 1924.

If the latter statements are correct, the rotation of crops must play an important part in keeping the agriculture of the corn belt upon a paying basis. At first glance this may seem easy because of the great variety of crops that can be successfully grown in the corn belt. But the problem is not simply one of adopting a succession of crops that will meet the nitrogen requirements. There is an important limiting factor that must be reckoned with if we would meet with any degree of success in bringing about the adoption of systems of crop and soil management that will effectively meet the situation. That limiting factor is the great demand for corn. At present the demand for corn is such that from two-fifths to one-half the land in the corn belt is planted to corn every year. Bearing in mind the importance of the corn crop, rotations or cropping systems that will provide for the necessary supplies of organic matter and nitrogen must be built around corn as the major crop. The requirements call for a considerable amount of legumes to be grown and returned to the land, either directly or in the form of manure. Fortunately, there are several valuable legumes that are well adapted to the conditions of the corn belt. How to fit them in is the problem.

In many cases the rotations now practiced are based upon convenience in management rather than upon any scientific principle as regards the ultimate effects upon productivity. The corn and oats rotation is convenient in considerable portions of the corn belt, but it is not desirable in its effect upon the land and the corn and oats farmer finds the fertility of his soil going down. In some sections corn, wheat, and clover makes a convenient rotation from the viewpoint of management, but from the viewpoint of production a poorer place for wheat could not be devised, especially where the wheat is seeded in the standing corn as is generally the case. Corn, oats, and clover is another rotation which provides for a change of crop and is simple and convenient, but oats is a profitable crop only in the northern portion of the corn belt. A four-year rotation of corn, oats, wheat, and clover or mixed clover and timothy is practiced in the northern or more particularly in the northeastern portion of the corn belt, where both of the small grains do well and where corn is not such an outstanding crop, but for the major portion of the corn belt this rotation has too small a proportion of corn to satisfy the farmer because corn is the most profitable crop of the four and for other reasons he wants more of it. The same objection applies to other four-year rotations with only one crop of corn. Most of the rotations that have been suggested by the experiment stations are objected to for the same reason and are not used to any considerable extent. It seems necessary, or at least desirable, to have corn in the rotation at least every three years or, in other words, to have one-third of the land in corn every year. Unfortunately, the regular rotation legumes, like red clover, cannot satisfactorily follow corn as they follow wheat or oats, and one or another of the small grain crops must be introduced and the rotation lengthened in order to utilize these legumes. The corn grower with rotation experience knows that it is important to so arrange his succession of crops as to have corn follow a legume

How to keep a sufficient amount of corn in the rotation and yet have it contain enough legumes to provide the needed nitrogen is the question. The solution seems to lie in the use of legumes as cover crops or inter-crops to be plowed under. For this purpose soybeans and sweet clover seem best adapted. Soybeans can be planted with the corn or between the corn rows for plowing under where the corn is to be followed by a second crop of corn or some other spring-planted crop. Sweet clover can be seeded in small grain in the spring and plowed under the following spring for corn Winter rye may be seeded in standing corn in the fall to save nitrogen from leaching and to provide additional organic matter for plowing under the following spring. Many farmers are following one or another of these practices to good advantage. Thus we may have several rotations supplemented with cover crops that will provide in a fair way for maintaining organic matter and nitrogen supplies and at the same time have a sufficient proportion of corn.

With a livestock system of farming, where the corn can be manured regularly and with the use of some fertilizer, especially phosphate, it seems possible to maintain fertility on good corn land with a rotation of corn, corn, wheat, and clover where a cover crop can be seeded in the first corn crop and the second corn crop cut off so that a good seedbed can be prepared for the wheat. Where soybeans can be utilized, a five-year rotation of corn, corn, soybeans, wheat, and clover may be successfully managed. Cover crops for plowing under can be seeded in both corn crops, and if manure and phosphate are applied for the corn and a good complete fertilizer for the wheat, no trouble should be experienced in maintaining good yields.

There is still some demand for grain farming systems of cropping. With sweet clover as an inter-crop it may be possible on good soils to practice a two-year rotation of corn and oats or corn and wheat where sweet clover is seeded in the small grain to be plowed under in the spring for corn. Some farmers are attempting this. Their success will depend upon the practicability of getting a satisfactory growth of sweet clover. If the process of making artificial manure from straw proves practical, this would help such a short rotation without the feeding of livestock.

One of the great stumbling blocks in carrying out satisfactory systems of cropping on many if not most corn belt soils is soil acidity which interferes with the growth of some of the best legumes. The clovers, sweet clover, and alfalfa will not thrive in acid soils. Soybeans and cowpeas will get along without liming and may be used to supply considerable amounts of leguminous material, but the only real remedy for such cases is liming the land as soon as possible. On acid soils, therefore, liming must become a part of the system of soil treatment in order that the more valuable legumes may be satisfactorily utilized in crop rotations Perhaps the most important principle to keep in mind in arranging crop rotations in the corn belt is that corn should follow a legume which provides a large amount of highly nitrogenous residue for plowing under. It is very important, therefore, that the land should be put in condition to grow such legumes as clover, alfalfa, and sweet clover and for these the acid soils must be limed.

The ways in which crop rotation helps to maintain productivity need not be recounted here, but it may be well to call attention to the fact that crop rotation alone cannot keep up the fertility of the soil. The production of larger crops, made possible by rotation, removes larger amounts of plant food from the soil. This cannot be indefinitely continued unless proper attention is given to the use of manures and fertilizers. The nitrogen required by the non-leguminous crops may be provided by including a sufficient proportion of legumes in the rotation, but rotation cannot supply the other plant foods in which the soil may be deficient. Corn belt soils are notably deficient in phosphorus and after a few years of cropping this element must be replenished from outside sources. Excepting the mucks, corn belt soils are well supplied with potash, but as a rule it becomes available too slowly to maintain maximum yields for any great length

TABLE 4.—*Crop rotation yields and financial statement, average 1916–1925, at the Indiana Experiment Station.*

	Average crop yields, 1916–1925					Average returns per acre per year[c]		
Cropping system[a]	1st corn, bushels	2nd corn, bushels	Wheat or oats, bushels	Soybeans, bushels	Hay, pounds	Value of crops	Cost of fertilizer	Net returns
1 C. W. Cl	51.3	—	24.8	—	3,639	$28.88	$1.43	$27.35
2 C. O. Cl.	58.8	—	44.6	—	3,197	24.11	1.43	22.68
3a C. C. W. Cl. seed	55.1	48.5	22.7	1.04[b]	—	28.38	1.35	27.03
3b C. C. W. Cl. hay	56.1	48.1	23.1	—	3,426	29.82	1.35	28.47
4 C. W. A	59.2	—	24.5	—	5.151	33.37	1.43	31.94
5 C. S. W.	50.3	—	31.2	20.6	—	34.58	1.43	33.15
6 C. W. Sw. Cl	54.5	—	26.9	—	3,017	29.24	1.43	27.81
7 C. S. W. Cl.	60.6	—	30.6	21.2	3,545	32.89	1.07	31.82
8 C. W. Cl. T.	59.5	—	25.7	—	8,179	30.05	1.07	28.98
9 C. C. S. W. Cl.	61.2	55.2	31.8	21.8	3,551	34.47	1.08	33.39
10 C. C. W. A. A. A.	64.4	57.1	32.1	—	20,516	40.93	2.07	38.86

[a] C = Corn, W = Wheat, O = Oats, Cl = Clover, S = Soybeans. Sw.Cl = Sweet Clover, A = Alfalfa, T = Timothy.

[b] Clover seed.

[c] In computing the financial results corn has been valued at $.60, wheat at $1.25, oats at $.35, soybeans at $1.50, and clover seed at $15.00 per bushel; hay at $12.00, corn stover at $3.00, oats straw at $3.00, and wheat straw at $2.50 per ton. Fertilizer constituents have been charged as follows: Nitrogen at $.25, potash at $.06, and phosphoric acid at $.07 per pound.

of time where only the crop residues go back to the land. Ordinarily, therefore, some system of soil management must be practiced whereby most of the phosphorus and a considerable portion of the potash removed in crops is returned to the land. Without such returns, the full benefits of crop rotation cannot be secured. A good example of this may be found in the experiments on the agronomy farm of the Indiana Experiment Station. This farm fairly represents the corn belt section of Indiana. In a corn, wheat, and clover rotation started in 1915 the crop yields on the untreated plats have fallen off over one-third in 10 years, showing that rotation alone cannot maintain productivity. The last crops harvested on the untreated plats were 46.3 bushels of corn, 13 7 bushels of wheat, and 2,320 pounds of hay as compared with 72 4 bushels of corn, 33 0 bushels of wheat, and 3,640 pounds of hay on the land which has received 6 tons of manure for the corn and 300 pounds of 2- 12- 8 fertilizer for the wheat.

As practical examples of what may be expected from different rotations of crops, at least in the Indiana portion of the corn belt, it may be well to call attention to the results (Table 4) secured in a series of crop rotation experiments on the agronomy farm at Lafayette, where reasonable amounts of manure and fertilizer are used

In each rotation manure is applied at the rate of 1,000 pounds per 1,000 pounds of produce removed other than the wheat and oats grain and half the alfalfa hay in rotation 10. Where wheat appears after corn, 2 tons of the manure are applied as a top-dressing on the wheat in winter The rest of the manure is plowed under for corn. Wheat after soybeans receives the soybean straw as a top-dressing in winter. Where two crops of corn appear, the second crop corn stalks are removed Otherwise, the corn stalks remain on the ground. In rotation 5 clover is seeded on the wheat and plowed under for corn. All wheat and oats crops receive 200 pounds of 2- 12- 4 fertilizer and all corn receives 100 pounds of 16% acid phosphate in the row, except in rotation 10, where each corn crop receives an extra 300 pounds of acid phosphate to provide for the needs of the three years of alfalfa. The second corn crop also receives 100 pounds of muriate of potash for the sake of the alfalfa.

It may be well here to call attention to a new problem in crop rotation that now confronts the corn belt farmer due to the advent of the European corn borer. Seeding wheat in standing corn will have to be discontinued. This may mean the passing of the three-year rotation of corn, wheat, and clover which is now practiced in many sections. The only chance remaining of seeding wheat after corn will be in those cases where the corn can be cut off and the remaining stubble thoroughly masserated before wheat seeding time. This will not be practicable in many cases and it looks as though wheat will have to be given a different place in the rotation and corn will have to be followed by a crop that will permit of plowing under the corn stalks or otherwise destroying them in time for seeding. The present practice of seeding oats in corn stalk ground without plowing will also have to be discontinued unless practical means are found to clean up thoroughly all corn plant remains left in the field or otherwise make them harmless before oats seeding time. The extra labor and difficulties involved in completely cleaning up the corn fields will doubtless tend to reduce the corn acreage and bring about important modifications in systems of cropping. However, if a fair proportion of corn can be maintained, this may not be an unmixed evil in that it may help solve some of the present crop rotation difficulties arising out of too much corn and not enough soil improvement crops on the majority of corn belt farms

SUMMARY

The same basic principles of crop rotation apply in the corn belt as on other soils in other localities Alternation of crops, including legumes at frequent intervals, is fundamental to the maintenance of a profitable agriculture.

Continuous corn or corn and other grain growing, with little return of plant food in manure or fertilizer, has greatly reduced the fertility of the soil on many if not most corn belt farms

The most important losses in fertility have occurred in the reduction of the effective organic matter and nitrogen content of the soil. These constituents are especially important because the production of corn, the most important crop, uses them up in large amounts.

Corn is the principle crop of the corn belt and must be recognized as such and provided for in any systems of crop rotation proposed for general use in this region. The large proportion of corn demanded by the farmer makes the arrangement of rotations that will satisfactorily maintain soil fertility unusually difficult.

The greatest problem in the agriculture of the corn belt, so far as crop production is concerned, is the maintenance of adequate supplies of organic matter and nitrogen in the soil. The climatic conditions of this region are highly favorable to rapid decomposition and nitrification and the tillage operations required in corn culture greatly enhance these processes.

To meet the heavy requirements of organic matter and nitrogen, crop rotations must be so arranged and managed as to bring in the rank-growing legumes as frequently as possible, either as full crops or as inter-crops, while at the same time maintaining a large proportion of corn in the cropping system.

To do this satisfactorily, the acid soils must be limed and manures and fertilizers, especially phosphate, must be utilized much more extensively.

5. CROP ROTATION IN THE GREAT PLAINS AREA

H. L. WALSTER

(This topic was discussed by Dean Walster as a part of the symposium and he had hoped to be able to prepare a paper on the subject for publication in the JOURNAL, but up to the time of going to press has been unable to do so.—EDITOR.)

6. CROP ROTATION IN RELATION TO SOUTHERN AGRICULTURE[1]

M. J. FUNCHESS[2]

INTRODUCTION

It is generally accepted that the acre yield of a given crop largely determines the unit cost of production of that crop. When large yields are obtained by the use of the best known methods, or due to natural fertility of the soil, the cost of production per unit is less than where low yields are obtained. Cotton production cost studies made by the U. S. Department of Agriculture illustrate this point in a very striking manner. Large yields per acre, economically obtained, make it possible for some farmers to secure a profit on their operations even in times of relatively low prices for their crops; while low yields preclude the possibility of profit when prices are low and afford but small profits when prices are relatively high. The use of suitable crop rotation and the application of adequate amounts of the right kind of fertilizer are the most important factors in obtaining high crop yields economically.

Weir (5)[3] has made a study of several rotation experiments and concludes that, "Including all crops and soils considered, crop rotation is practically 75% as efficient as the use of fertilizer in effecting increases in crop yields." Weir found that where corn, wheat, and oats only are considered, rotation has been about 90% as effective as fertilizer in effecting increases in yields. In this study it is believed that Weir has not given sufficient consideration to (a) the natural fertility of the soil under consideration, (b) the kind of crops making up the rotation, and (c) the kind and amount of fertilizer used in the experiments and the part that these may play in increasing crop yields by their influence on the leguminous crops in the rotation.

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[1] Paper read as a part of the symposium on "Crop Rotation" at the meeting of the Society held in Washington, D. C., November 19, 1926.

[2] Director, Alabama Experiment Station, Auburn, Alabama.

[3] Reference by number is to "Literature Cited," p. 565.

It is the purpose of this paper to show (a) that the chief value of crop rotation is determined quite largely by the legumes in the rotation and (b) that the production of legumes may depend quite largely on the addition of mineral fertilizers and lime. For the purpose of illustrating the importance of the above-mentioned points some data will be presented from rotation experiments conducted by the Alabama, Pennsylvania, Ohio, Delaware, and South Carolina Experiment Stations.

BENEFITS OF CROP ROTATION

The probable benefits to be had from a rotation of crops may be listed as follows: (a) Maintenance of crop yields; (b) control of weeds, insects, and diseases; and (c) prevention of soil erosion. The following pages are devoted to a discussion of these topics in the order given above.

MAINTENANCE OF YIELDS

The emphasis placed on the value of rotation alone as a means of increasing crop yields may be justified under certain conditions; nevertheless, there is evidence to show that crop rotation alone may fall far short of maintaining yields. The natural fertility of the soil and the kinds of crops grown must be considered. It is conceivable that yields may be maintained for a long time through rotation alone, if the soil contains a large amount of the mineral nutrient elements, if it has a favorable reaction, and if legumes have a permanent place in the cropping plan. On the other hand, a rotation scheme that does not include a legume, when practiced on poor land, will not result in large crop yields. Under average conditions existing in the South, a rotation that does not include a legume certainly will not be very beneficial. Southern soils are usually deficient in nitrogen, phosphorus, potash, and active lime. The value of crop rotation, therefore, will depend largely on the amount of legumes that are grown in the rotation and the production of legumes may depend on the addition of mineral fertilizers and lime. If crop rotation is to be of much value, all of the conditions essential to the production of good crops of legumes must be met. The addition of mineral fertilizers and lime may be necessary for this purpose, even though the major crops in the rotation do not respond very much to the direct application of such materials.

These statements may be very well illustrated by considering some of the crop yields obtained in rotation studies made at the Alabama Experiment Station. The cropping scheme is as follows: First year, cotton followed by fall-planted oats; second year, oats followed by peas, which are disked in, and vetch planted in the fall; third year, corn, with cowpeas planted in the middles at the last cultivation. In the early fall, vetch is planted on the corn plats by disking down the corn stalks and pea vines, or by the use of a three-row drill run in the corn middles. This plan permits the use of four legume crops in the three-year rotation.

There are four plats in the rotation that are of special interest in this study. Plat A receives mineral fertilizers and legumes are included as indicated above. Plat B receives the same mineral fertilizer as A, but legumes are omitted. Plat C receives no fertilizer, nor legumes; while plat I receives no fertilizers, but is planted to legumes according to the scheme indicated. These four plats afford comparison of (a) the effect of legumes with and without mineral fertilizers, and (b) the effect of fertilizer with and without legumes. The plat treatments, cropping plan, and crop yields for 1926 are given in Table 1.

TABLE 1.—*Yields of cotton, corn, and oats for 1926, crops grown in 3-year rotation, Alabama Experiment Station.*

	Fertilzers per rotation[a]			Yields per acre[b]		
Plat	Acid phosphate	Muriate	Cropping system	Cotton *Pounds*	Corn *Bushels*	Oats *Bushels*
A	480	100	3-year rotation with leugmes	918	34.9	10.1
B	480	100	3-year rotation no legumes	152	7.4	5.4
C	None	None	3-year rotation no legumes	168	11.3	6.9
I	None	None	3-year rotation with legumes	706	22.7	9.0

[a] One-half of fertilizer applied to cotton and other half to corn.

[b] Yields from plats A, B, and C are for the thirteenth crop year and those from plat I for the sixteenth crop year of these experiments.

The yield data given in Table 1 show that crop rotation without the use of legumes or fertilizers is producing a very low yield of the three main crops in the rotation. The addition of mineral fertilizers without legumes in the rotation (plat B) has given no increase in yield of either of the major crops. The nitrogen deficiency is so great in the soil used in these experiments that there is no increase in yield whatever from the application of minerals alone. Plat A receives the same mineral fertilizer treatment as plat B, but legumes are included in the cropping plan. The increase in yield attributed to the legumes amounted to 766 pounds of cotton, 27.5 bushels of corn, and 4.7 bushels of oats. These figures strikingly illustrate the importance of the legume crop in a rotation system for southern conditions. A comparison of the yields on plat A and plat I proves the importance of the minerals in a rotation system due to their effect on the legumes. Plat I, which receives no mineral fertilizer, produced a poor growth of both peas and vetch. This reduced growth, due to the omission of mineral fertilizer and the consequent low yields of legumes, is reflected in the major crop yields, particularly the cotton and corn. This indirect effect of the minerals amounted to an increase of 212 pounds of cotton, 12.2 bushels of corn, and 1.1 bushels of oats.

The low yields of oats in these experiments are very interesting. The crop of oats follows cotton in the rotation which precludes the planting of a legume crop for the direct benefit of the oats. It would appear from these results that the decomposition of legume crops turned under is very rapid, and that there is very little residual effect on crops grown the second season after a legume crop has been plowed in.

The soil on which this rotation is located is Norfolk sandy loam and is typical of millions of acres of land in the South. It is believed, therefore, that the above results are indicative of the importance of legumes in the cropping system of this territory and of the part that mineral fertilizers play in such cropping systems. Crop rotation alone without including legumes will be of very little benefit in southern agriculture, if these experiments may be taken to illustrate average conditions.

The chief objects of rotation and fertilizer studies should be to determine the most economical means of maintaining the crop-producing power of good land and of increasing the productive power of poor land. Over a long period of years it is probably more difficult to attain the first than the second object. A given treatment may actually cause increased yields on poor land but fail to maintain the level of production on very fertile land. It is very important, therefore, to consider the level of fertility at the beginning of the experiment and the trend of yields over a long period of time. It is not sufficient to know that crop rotation alone has maintained the yield of corn twice as high as has the continuous culture of corn. The yield in either case may be too low to be profitable. Further, the yields in each case may be steadily declining, even though the crop in rotation be producing twice as much as that obtained under continuous culture. With this idea in mind it is very interesting to examine some of the rotation and fertilizer results obtained by several experiment stations north of the cotton belt.

Crop yields obtained from the Pennsylvania rotation experiments[4] for 40 years make possible a very interesting study of yield trends under varying conditions of manuring and fertilizing. To conserve space average yields of some of the plats for the first eight years and last eight years only will be considered. In making the study those plats have been considered which tend to show the importance of the legume in the rotation and the importance of the mineral fertilizer on the yield of the leguminous crop. The yield data for selected plats are given in Table 2.

Considering the yields from the untreated plats, it is found that during the last eight-year period there have been produced 26.2 bushels of corn, 12.0 bushels of oats, 3.9 bushels of wheat, and 1,574 pounds of hay less than was produced during the first eight-year period. It should be noted that the yield of hay on the unfertilized plats was approximately half as large during the last period as it was during the first. Those plats that were fertilized with such materials as dried blood alone or muriate of potash or land plaster applied singly are now producing about half as much clover as they did during the first period; and in each case there have been very similar declines in production of all crops as that noted on the check plats.

The plats treated with phosphatic fertilizer or with limestone are now producing roughly two-thirds as much clover as was obtained during the first eight years. On these plats the yield of corn has declined considerably, but not to the extent that is found on those plats mentioned above. The plat receiving only phosphatic fertilizer has maintained the yield of oats and wheat, while that receiving ground limestone alone has suffered a small decline in yield of oats and as serious a decline in yield of wheat as that obtained from the unfertilized land. Turning now to the average yield of four plats treated with phosphatic and potassic fertilizer it will be noted that the yield of clover has been nearly maintained throughout the 40-year period. In this case the yields of oats and wheat are higher than they were in the beginning, while the corn crop has dropped from 60 to 51.7 bushels. It would appear from these results that the application of mineral fertilizers has nearly maintained the clover yield and along with it the yield of other crops grown in the rotation.

[4] Professor C. F. Noll, Department of Agronomy, Pennsylvania State College, kindly supplied by letter the data on which this discussion is based. Yields of corn, oats, and wheat were calculated from figures thus obtained.

TABLE 2.—*Average yields of first and of last eight years of a 40-year period for crops grown in rotation at the Pennsylvania Experiment Station.*

Plat	Treatment per rotation	Amount of elements per rotation			Corn		Oats		Wheat		Hay	
		N	P_2O_5	K_2O	First period	Last period	First period	Last period	First period	Last period	First period	Last period
					Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Pounds*	*Pounds*
1, 8, 14, 24, 36	None	0	0	0	53.3	27.1	42.4	30.4	13.3	9.4	3,174	1,600
2	Blood	48			53.7	23.2	42.6	30.8	13.6	10.1	2,876	1,450
3	Bone black		96		53.6	38.9	42.9	42.4	13.9	15.3	3,248	2,216
4	Muriate			200	54.3	19.6	43.3	30.2	12.4	8.0	2,918	1,256
7, 15, 25, 29	Bone-muriate		96	200	60.0	51.7	46.7	50.1	16.2	19.7	3,652	3,295
34	4 tons CaCo,				51.5	46.5	44.3	36.8	13.7	9.9	3,424	2,048
13, 33	320 pounds land plaster				52.9	27.3	42.5	30.8	13.0	9.6	3,157	1,433

TABLE 3.—*Average yields of first and last 10 years of a 30-year period for crops grown in rotation at the Ohio Experiment Station.*

Plat	Treatment per rotation		Corn			Oats			Wheat			Clover			Timothy		
			First period	Last period		First period	Last period		First period	Last period		First period	Last period		First period	Last period	
	Phosphorus	KCl		Unlimed	Limed		Unlimed	Limed		Unlimed	Limed		Unlimed	Limed		Unlimed	Limed
			Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Check	None	None	31.3	18.7	29.5	29.6	28.9	38.8	8.9	9.4	15.0	1,651	765	1,750	2,443	1,757	2,854
2	320		38.9	25.9	32.2	30.2	39.8	45.1	15.5	18.7	24.1	2,069	1,200	2,210	2,842	2,240	3,573
3		260	35.5	24.6	42.4	34.2	32.1	41.8	10.4	10.4	16.3	1,851	945	1,824	2,807	1,893	3.244
8	320	260	42.3	41.8	47.0	39.6	43.9	52.0	17.8	19.0	27.3	2,241	1,421	2.655	2.795	2,405	3,776

Those single applications that failed to maintain the clover yield have also failed to maintain the yields of the major crops. To be sure, the fertilizer materials applied may be influencing the yields of the crops grown in this rotation, due to their direct fertilizer effect, but it is believed that the data sustain the point that crop rotation alone is not sufficient to maintain yields at a high level of production unless the land used is naturally fertile enough to maintain the production of clover also. The uniformity of the plat yields during the first period was rather remarkable. Wide differences in yields developed during the 40 years, however, as is shown by the average results of the last eight-year period In a general way the differences found during the last period parallel the differences in yields of clover.

Some of the data (6, 7) reported from the five-year rotation experiments at Wooster, Ohio, are presented in Table 3. These data afford material for a study similar to that made of the Pennsylvania experiment. In considering these results it should be remembered that the initial level of production of the Ohio plats was considerably lower than that of the Pennsylvania plats For this reason, a given treatment may maintain the level of production on the Ohio plats, but fail to keep up the high initial yield of the Pennsylvania plats. Yields for the first 10 years are the average for both the limed and unlimed plats Lime was not added until near the close of the period, however, and no great error is involved if the yields for this period are considered to be from unlimed land Yields from the limed and the unlimed plats for the last 10 years of the 30-year period are considered separately On the untreated land, the yields of corn, clover, and timothy have definitely declined, the corn yield dropping from 31.3 to 18 7 bushels Yields of oats and wheat have remained practically the same as at the beginning. There has been a marked decline in the yield of clover on the unlimed plat treated with potash alone. On this plat the yields of corn, oats, and timothy have all declined considerably, but the low yield of wheat has been maintained. The yield of clover on unlimed land fertilized with acid phosphate alone has been considerably higher during the last 10 years than that of the check plats or of the plat receiving potash only. In this case the decline in yields of oats, wheat, and timothy had been smaller than the two plats already mentioned, while the yield of corn is quite similar to that obtained from the potash-treated plat. Plat 8 received both phosphate and potash and on the unlimed land the clover yield has held up somewhat better than that of the plats mentioned above. With this treatment the yield of corn has been approximately maintained and that of oats and wheat slightly increased. The timothy yield is the only one that is noticeably lower during the last period than it was in the first.

Turning now to the limed plats, it will be noted that the yield of clover on each plat has either been maintained or slightly increased. On the unfertilized plats the addition of lime has maintained the yield of corn and increased the yields of oats, wheat, clover, and timothy. With the exception of corn the yields of all crops were higher on the limed and phosphated plat during the last period than for the first period. The limed plats receiving both phosphate and potash have produced more clover during the last than in the first period. With this treatment there have been definitely increased yields of corn, oats, wheat, and timothy. Since lime does not add any of the common fertilizer constituents and since its application has produced rather striking increases in yield of clover, these Ohio data indicate quite strikingly the necessity for such treatment as will maintain or increase the yield of clover if the yields of the other crops grown in rotation are to be maintained at a satisfactorily high level. These results also indicate that under crop rotation alone the yields of most crops will decline unless the level of production at the beginning is low. The wheat yields on unlimed check plats have been practically maintained, but the initial yield was so low that this result might be expected. From an economic standpoint, it is much more important to know the nature of the treatment required to maintain high levels of production or to raise the level of production on poor land than it is to consider the mere maintenance of yield if such initial yields be low. This idea may be illustrated by comparing the yields of wheat for the last 10-year period of untreated land in rotation and in continuous culture with that obtained in the same period but with rotation and phosphate, potash, and lime added. The untreated land in rotation averaged 9.4 bushels of wheat. Untreated land in continuous culture averaged 6.7 bushels of wheat, but with rotation, lime, phosphate, and potash treatments the average yield was 27.3 bushels of wheat. Similar comparisons with the other crops show somewhat similar results. It is obvious, therefore, that land treatment may be of much more importance than mere rotation of crops.

The Delaware Experiment Station (3, 4) has recently published some results from which it is possible to compare the yields of corn in rotation and continuous culture under several soil treatments. Some of these yields are reported in Table 4. Corn fields from untreated land in rotation and in continuous culture have been 42.5 and 16.7 bushels, respectively. In this rotation of corn, soybeans, wheat,

TABLE 4.—*A comparison of crops grown in rotation vs. continuous culture at the Delaware Experiment Station.*

	Average yield per acre of crops in				
	Rotation				Continuous culture
Treatment per rotation[a]	Corn 1908–23 *bu.*	Beans 1916–23 *bu.*	Wheat 1908–23 *bu.*	Hay 1908–23 *lbs.*	Corn 1908–23 *bu.*
None	42.5	13.3	10.4	2951	16.7
Acid phosphate, 750 pounds	41.0	13.8	15.8	3109	——
Muriate of potash, 270 pounds	65.8	21.5	16.3	3371	——
Acid phosphate, 750 pounds Muriate of potash, 270 pounds	71.4	23.9	22.7	4605	56.6[b]
Acid phosphate, 750 pounds Muriate of potash, 270 pounds Sodium nitrate, 350 pounds	77.5	28.3	28.9	5039	57.8[b]
Green manure only	——	——	——	——	23.2

[a] In four years corn in continuous culture received 1,000 pounds of acid phosphate, 500 pounds of sodium nitrate, and 300 pounds of muriate of potash.

[b] These plats received green manure in addition to the fertilizer treatment indicated.

and clover and timothy, the average yields of beans and hay on the untreated land have been 10.4 bushels and 2,951 pounds, respectively. It is not surprising that the yield of corn in rotation is higher than that in continuous culture on land that will produce such yields of the two legumes grown in the rotation. The addition of phosphorus and potash produced average yields of 23.9 bushels of beans and 4,605 pounds of hay. The yield of corn from this treatment has been 71.4 bushels. Under continuous culture of corn very interesting results have been obtained. The untreated land produced an average yield of only 16.7 bushels. A green manure crop alone produced an average yield of 23.2 bushels. But with green manure, phosphorus, and potash the average corn yield for the 16-year period was 56.6 bushels. It appears that the use of mineral fertilizers has caused an increase of 33.4 bushels of corn annually. In the rotation plats the yield of clover was materially increased by the addition of phosphorus and potash. It is very probable, therefore, that a large part of the effect of the minerals on corn in continuous culture was due to its indirect effect on the green manure crop grown between the corn crops. At any rate, it is very interesting to note that such high yields of corn may be produced by the relatively simple practice of green manuring, together with the addition of mineral fertilizers.

The South Carolina Experiment Station (1) has made a comparison of cotton grown in a rotation with corn and cowpeas and oats followed by cowpeas for hay with cotton grown continuously on the same land.

The experiments have been in progress for 12 years, but results for the last 6 years have not been published. The unpublished data have been supplied through the courtesy of the Department of Agronomy. In these experiments cotton in rotation fertilized annually with 800 pounds of fertilizer (plat 30), analyzing 8% phosphoric acid, 4% ammonia, and 4% potash, produced 1,870 pounds per acre during the first six years, but has declined to 1,196 pounds as the average for the last five years. With the same fertilizer treatment the cotton in continuous culture averaged 1,710 and 965 pounds per acre for the two periods, respectively. It will be noticed that the yield under both conditions has declined materially. A part of the decline may be due to the poor growth of peas in recent years. During the earlier years, the peas planted in corn usually made a very satisfactory growth. However, the pea crop has gradually become smaller from year to year and failed entirely in 1926. The peas following oats made as much as 2 tons per acre in some of the earlier years but have also gradually declined to a rather low level of production.

On unfertilized land (plat 31) cotton in rotation made an average yield of 1,570 pounds during the first period and 703 pounds for the second period. The unfertilized plat in continuous culture made yields of 1,382 and 329 pounds during the two periods under consideration. The yield from unfertilized, continuous cotton is now a little less than one-fourth as large as it was during the first 6 years of the 12-year period, but in the rotation the yield on the check plat has declined to slightly less than half that of the first period. Special attention is called to the high yield of cotton obtained during the first six-year period. When these experiments were started, the unfertilized plat in continuous culture produced a bale of cotton per acre which indicates that the initial level of production was much higher than that found under average conditions in the cotton belt. The marked reduction in yield of cotton in rotation and in continuous culture, whether fertilized or unfertilized, indicates the difficulty of maintaining very high *average* yields of cotton under southern conditions. The higher yields obtained in the rotation emphasize the importance of legumes in the cropping system, and the better maintenance of yield on the fertilized plats indicates the importance of fertilizers in southern agriculture. The South Carolina and Alabama results indicate that fairly high yields of crops may be produced economically through the use of fertilizers and crop rotation, provided legumes have a permanent place in the cropping plan.

CONTROL OF WEEDS, INSECTS, AND DISEASES

The advantages usually attributed to crop rotation include (a) better control of weeds, (b) addition of organic matter, (c) improvement in soil tilth, (d) prevention of erosion, and (e) better control of diseases, etc. These, and other benefits, are frequently mentioned, although there is little direct evidence available to support some of these supposed benefits.

It is doubtless true that crop rotation will aid in the control of many weed and insect pests and plant diseases. Cotton boll-rot may be much worse where the crop is grown continuously than if worked in rotation. Wilt, or black-root of cotton, is always more destructive on nematode-infested land, if cotton follows a crop that was a good nematode host plant On the other hand, the southern corn rootworm usually gives little or no trouble on average upland when corn is grown continuously, yet if corn follows vetch as a green manure crop in the rotation, the stand of corn may be almost completely destroyed by this worm. Nut grass is one of the most troublesome weed pests that the southern farmer has to control There is no practical crop rotation that will aid in the control of this weed as will the continuous production of cotton. These illustrations are given to show that some of the blanket statements in regard to the value of crop rotation may not be wholly correct

PREVENTION OF EROSION

The loss of soil by erosion is very heavy throughout a large part of the South. Much of the cultivated land is bare during the winter, at which time the rainfall is heavy. On the rolling lands erosion has removed a considerable part of the soil and has cut gullies in many fields. Some of the hilly soils have been so seriously damaged by surface washing that occasional abandoned fields are to be found, even though the land may not have been in cultivation for as much as 50 years. Duley (2) has shown that erosion losses are much lighter under crop rotation or sod than under continuous cropping to corn or bare fallow. Since conditions are very favorable for soil erosion in most of the southern states, it would seem that crop rotation involving non-cultivated crops would be highly beneficial in reducing erosion losses. These losses may be reduced if grain or winter legumes be used in the rotation.

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5. Weir, Wilbert W. A study of the value of crop rotation in relation to soil productivity. U. S. D. A. Bul. 1377. 1926.
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CONCLUDING REMARKS BY THE LEADER

W. W. Weir

From the facts presented in the papers and discussions, the following summary may be made:

The varying conditions which exist on a farm with respect to soil, feeding requirements, etc., usually call for flexibility in cropping rather than for any fixed cropping system, in order that the highest success in farming may be realized.

The facts presented point to three distinct rotation principles, namely, (1) soil fertility can best be maintained when intertilled, small-grain, and grass or leguminous crops are grown in the order named and in recurring succession on a given area of land; (2) soil condition and characteristics determine in a large degree what crops are best adapted to a particular soil; and (3) one kind of crop affects to a greater or less degree the growth of another crop which follows it.

The benefits which may be realized from proper rotation of crops are not fully appreciated by probably the majority of farmers. Permanent improvement in cropping systems can be effected only through a long educational campaign. In the corn belt, cotton belt, and on the Great Plains diversification and crop rotation are major factors in the establishment of a prosperous and permanent agriculture.

After 200 years of existing knowledge of proper rotation, the ideas of American agronomists with respect to rotations seem to agree with many of the ideas expressed by Arthur Young when modern rotation was only 40 years old. In "Rural Oeconomy," published in England in 1770, he wrote: "The common practice in many things points to much to be known experimentally, so that any man may be able to declare precisely in what degree it is valuable, and in what deficient."

"In what degree of merit are beans, peas, turnips, carrots, cabbages, and clover to be ranked as fallow or preparatory crops?"

"Clover requires good husbandry."

"After the clover comes the wheat which must infallibly suffer from the poverty of the clover crop."

"Wheat is ever the best after the best crops of clover."

"Turnips (cultivated crop) and clover, at the same time that they maintain great flocks of cattle, may be called the nurseries of corn (cereals)."

"The less corn (cereals) is sown, the more is produced."

NOTE

A METHOD FOR STORING SMALL QUANTITIES OF SEED CORN

Many growers store their seed corn on the ear throughout the winter in order to make a germination test of each ear indvidually prior to the time of planting. Corn which is exposed to the air fluctuates in moisture content with changes in atmospheric moisture and is also subject to mouse injury. With this in mind a test was made in the Plant Physiology Laboratory, University of Illinois, to obtain a simple method of storing small quantities of seed corn to reduce the chances for deterioration due to changes in atmospheric moisture and to mechanical injury.

Reid Yellow Dent corn was selected from the field in the fall of 1925 and was dried in a heated room until the moisture content was reduced to 9.9%. On December 2 of that same year it was placed in an uncovered metal container which was about half as large as a barrel. A layer of oats 4 inches deep was placed in the bottom of the container. Successive layers of ears of corn were then placed in the container with just enough oats to fill the spaces between the ears. A layer of oats 4 inches deep was placed on top of the uppermost layer of corn. One lot of corn which was used as a check was hung in the open air. Both the check lot and the uncovered container of corn and oats were placed on an open air porch sheltered from rain. Moisture determinations of the corn and oats were made at various intervals.

The oats contained 10.2% moisture at the beginning of the test. The moisture content of the corn which was used as a check increased rapidly from December 2 to December 5. The average relative humidity during this period was 84%. On December 10, after a period of eight days, the moisture content of the corn which was exposed to atmospheric moisture was 12.6%. The corn which was 4 inches below the surface of the oats contained 10.7% moisture, or about 2% less than the corn exposed to the atmosphere. On January

4 moisture determinations were made on both corn and oats at various depths in the container. The moisture content of corn suspended in the open air was 14.4% at that time. The oats at the surface in the container had a moisture content of 14.8%. At 4 inches and at 16 inches below the surface the oats contained 11.6% moisture, while corn at those depths contained 11.0% and 11.2%, respectively.

The moisture content of corn which was exposed to the atmosphere fluctuated with variations in relative humidity, while the moisture content of the corn stored in the oats increased very slowly. The moisture content of both oats and corn changed very little at a depth of 4 inches or more below the surface of the oats.

This method of storage prevents rapid fluctuation in the moisture content of corn and prevents mice from gnawing the crowns of the kernels. A germination test of each ear can be made just prior to planting. It is necessary that both corn and oats should have a low moisture content before storing the corn when this method is used.—H. W. ALBERTS, *Director of Alaska Experiment Stations, U. S. Department of Agriculture, Sitka, Alaska.*

ERRATUM

The formula on page 459 of the article by P. J. Olson in the May issue of this JOURNAL should read "$2T_x$" in the denominator instead of "2_x" as printed.

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OLD WORLD WEED INTRODUCTIONS[1]

P. B. KENNEDY AND ADELINE FREDERICK[2]

The ways and means by which noxious weeds become introduced are of much interest, especially to the agronomist and seed analyst, the former because he is generally placed with the task of eradicating them and the latter because he is expected to identify all impurities in imported seeds. The seeds which warrant the writing of this paper are impurities found in the seed of a leguminous plant, fenugreek, *Trigonella foenumgraecum*. It is an annual plant indigenous to and cultivated over a wide area in the Mediterranean region. It is also frequently mentioned in the agricultural literature of India where the crop is associated with the growing of cotton and the fodder used to feed work bullocks.

Fenugreek seeds are used for a number of purposes and, like the plants, have a strong and characteristic odor. Among the uses may be mentioned a yellow dye, medicine, perfumery, and, when ground up, as an ingredient of condition powders and poultry and stock foods. It is for the two last-mentioned purposes mainly that the seed is imported into the United States as an agricultural product. However, C. H. McCharles of the California State Food and Drug Laboratory states that fenugreek is used to a considerable extent in confectionery and particularly as an artificial maple flavoring.

Seed of fenugreek may be purchased from seedsmen in Europe and occasionally is offered for sale by seedsmen in both the eastern and western parts of the United States. Sometimes seed imported for stock food purposes gets into the trade for use as a crop to plant and herein lies the danger of introducing noxious weeds.

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[1] Contribution from the Department of Agronomy, College of Agriculture and Agricultural Experiment Station, University of California, Berkeley, Calif. Received for publication March 4, 1927.

[2] Professor of Agronomy and Agrostologist of the Station, and Laboratory Assistant, respectively.

A 50-pound lot of fenugreek seed was purchased in the United States from a poultry food company in 1922, sampled by means of the Boerner Seed Sampler, and 272 grams examined for seeds other than fenugreek. The following list of seeds is arranged numerically according to the number of seeds of each kind found in the sample.

Name	Family	Number of seeds
Bupleurum subovatum	Umbelliferae	150
Galium tricorne	Rubiaceae	113
Linum usitatissimum	Linaceae	29
Vaccaria vaccaria	Caryophyllaceae	20
Undetermined seed (Fig. 6)	———	20
Cichorium intybus	Compositae	12
Scandix pecten-veneris	Umbelliferae	12
Cereals (wheat and barley)	Gramineae	12
Undetermined seed (Fig. 7)	———	6
Krubera peregrina	Umbelliferae	6
Phalaris minor	Gramineae	4
Torilis nodosa	Umbelliferae	4
Emex spinosus	Polygonaceae	4
Undetermined seed (Fig. 8)	———	4
Convolvulus arvensis	Convolvulaceae	3
Bifora testiculata	Umbelliferae	2
Undetermined seed (Fig. 9)	———	2
Malva parviflora	Malvaceae	1

As the seeds listed above are all indigenous to the Mediterranean region it is evident that the fenugreek seed containing them was grown in southern Europe. The weed most to be feared because of its spiny and noxious character is *Emex spinosus* (Fig. 1) which is understood already to have made its appearance in at least one section of California.

Seeds found in the 50-pound lot of seed but not represented in the 272 gram sample were as follows: *Zea mays*, *Bromus tectorum*, *Echinochloa crus-galli*, *Vicia monanthos*, *Vicia* spp., *Lathyrus* sp., *Lotus* sp., *Salvia sclarea*, *Antirrhinum* sp. capsules, *Centaurea sicula*, *Calendula* sp., *Lithospermum arvense*, *Raphanus raphanistrum*, *Rumex* sp., *Beta vulgaris*, and several other seeds as yet unidentified.

Descriptions of most of the plants listed or their seeds are to be found in the literature of the United States Department of Agriculture or that of the agricultural experiment stations.

The following, however, are not to be found in American literature so are described here in detail, accompanied by illustrations in Plate I.

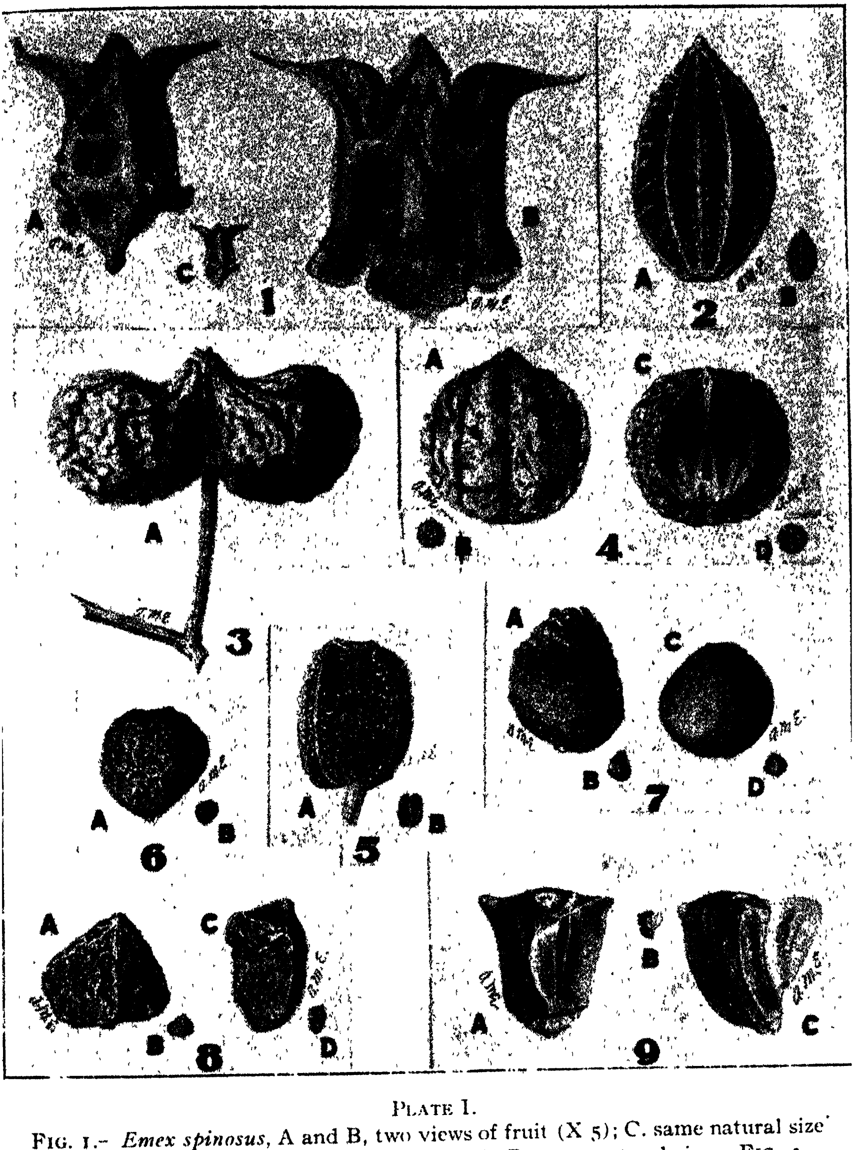

PLATE I.

FIG. 1.– *Emex spinosus*, A and B, two views of fruit (X 5); C, same natural size. FIG. 2.– *Krubera peregrina*, A, fruit (X 5); B, same natural size. FIG. 3.– *Bifora testiculata*. A, twinned fruit (X 5); B, same natural size. FIG. 4.–Same as Fig. 3. A, dorsal view of carpel (X 5); B, same natural size; C, commissural plane of carpel (X 5); D, same natural size. FIG. 5.–*Bupleurum subovatum*. A, fruit (X 5); B, same natural size. FIGS. 6, 7, 8, and 9.– Unidentified seeds. A and C (X 5); B and D, natural size.

EMEX SPINOSUS (L.) CAMPD. (Fig. 1)

A smooth annual plant, 1 to 2 feet tall, resembling and allied to dock, *Rumex*, producing many forked angular stems from the crown, long-petioled ovate-truncate leaves, membranous toothed stipules, and formidable spiny burs about a quarter of an inch long in the axils.

Annual, glabrous, flowers monoecious or perfect; staminate, pedicelled, with 4-6 stamens, perianth 3-6 parted, lobes equal, spreading; pistillate sessile, perianth triangular-urceolate, 6-toothed, the three outer spiny and curved outward, the inner ovate-triangular, connivent: leaves ovate to ovate-oblong, entire, cordate to truncate at base, 6 cm long and 2.5 cm wide, petioles 6-9 cm long. Achene free, trigonal, light-brown enclosed by the perianth, embryo peripheral, radicle at upper end of seed; endosperm granular, farinaceous, starch grains, large, cylindrical, 0.2 to 0.5 mm long.

Distributed throughout the Mediterranean region, South Africa and Australia.

KRUBERA PEREGRINA L. (Fig. 2)

A smooth annual plant from 1 to 2 feet tall with angled, grooved, branching, rigid leafy stems, oblong, much-divided decurrent leaves, small white flowers and flattened corky-ribbed roughened seeds.

Leaves oblong, shortly decurrent tripinnasected, lobes, linear, entire; umbels in heads with about four rigid rays, pedicels very short and thick, involucels short, triangular-lanceolate, entire; calyx 5-toothed; petals obovate-emarginate, with inflexed tips. Fruit dorsally flattened, elliptical, somewhat acute, 5 mm long and 3 mm wide; carpels with 5 thick, corky, elevated ribs, the lateral ones marginal. Oil tubes under the ribs obscure, carpophore bi-parted, commissure flat.

In cultivated clay soils in Greece and Palestine and other countries bordering the Mediterranean Sea.

BIFORA TESTICULATA (L.) D. C. (Figs. 3 and 4)

A smooth, strong-smelling annual plant 1 to 2 feet tall with angled stems, much divided leaves, white flowers, twinned fruits and hemispherical seeds. The interior face of the seed is perforated concave and deeply grooved, while the exterior is convex and roughened. The plant resembles and is allied to coriander (*Coriandrum*).

Leaves 4-8 cm long, bipinnasected, the radical petioled, the cauline sheathed and scarious-margined dichotomously divided into oblong-cuneate, acute, segments, umbels from all the axils, exceeding the leaves, rays 2-3, umbelules 2-3 flowered; calyx wanting, petals curved with inflexed tips, fruit twinned, retuse at base, broader than long, 6 mm x 3 mm stylopodium minute, conical, styles recurved; carpels sub-globose, the interior face perforated and concave, pericarp tuberculate-rugose, ribs obscure, oil tubes none.

Countries bordering the Mediterranean Sea.

The variety *microcarpa* has fruits about one-half the size of the species and occurs in Palestine. *Bifora radians* has umbels with

5–7 rays which are many flowered. The styles are three to four times the length of the stylopodium. It extends from Asia Minor to southern France and Germany.

BUPLEURUM SUBOVATUM LINK. (Fig. 5)

An erect, smooth, pale, branching annual plant growing from 1 to 2 feet tall with roundish-pointed leaves 1 to 2 inches long, surrounding the stems or the lowest narrowed into a leaf-stalk. The flowers are greenish yellow and the seeds angled and roughened.

It is known as hare's ear, thoroughwax, thoroughwort, or modesty.

Radical leaves oblong, entire, tapering at base, the cauline oblong to ovate perfoliate, mucronate; umbels terminal with 2–5 rays, involucels broad, ovate-orbicular, mucronate, 5–7 veined, longer than the flowers, calyx teeth wanting; petals broadly cuneate curved and inflexed at the apex, fruit prismatic, granular-tuberculate, about 3 mm long and 2.5 to 3 mm wide, ribs filiform, the lateral ones marginal. Carpels not readily separable; oil tubes none.

It is distributed throughout the Mediterranean region and was the most prevalent seed found in the fenugreek sample.

Bupleurum rotundifolium has been naturalized from Europe and occurs in cultivated fields in the eastern and southwestern parts of the United States. It can be distinguished from *B subovatum* by its smooth instead of roughened fruits.

A number of the seeds of these weeds have been grown in the greenhouse, although the age of the seeds is at least four years. The ones represented in Figs, 6, 7, 8, and 9 did not germinate. Fig. 6 represents a black seed with the seed coat irregularly and indefinitely reticulated, embryo through centre, cotyledons and radicle not easily differentiated.

Fig. 7 represents a red seed with a hard seed coat covered by a loose fibrous layer which is brownish and appears as if succulent when fresh Embryo straight through centre. Cotyledons and radicle straight through centre, not readily differentiated.

Fig. 8 represents a black irregularly angled seed with flat sides; seed coat undulate and roughened; embryo through centre, cotyledons and radicle not differentiated.

Fig. 9 represents a yellowish, four-sided seed with wings at the angles and presenting the appearance of a piece of stem, the embryo is pear-shaped and situated directly through the centre. Cotyledons and radicle not differentiated.

In all about 40 different kinds of seeds other than fenugreek have been discovered in this one shipment. Even if 1 of the 40 should become established and should happen to be a noxious species like the caltrop or puncture vine, *Tribulus terrestris*, the cost of eradication, even if feasible, would be excessive.

EFFECT OF VARIOUS FERTILIZERS AND LIME ON COMPOSITION OF SOYBEANS[1]

George L. Schuster and J. M. Graham[2]

The increased popularity of soybean seed as a source of concentrates for livestock feeding and as a source of oil for industrial purposes has given rise to the question as to whether or not the composition of beans may be influenced by fertilizers. Most investigators have reported that lime increased the protein content of the beans and decreased the oil content, but the results as to other soil amendments have not been so conclusive.

The present investigations were conducted on soybeans grown in the regular rotation on the fertilizer plats of the Delaware Experiment Station for the 1921, 1924, and 1925 crops. These plats have received the same treatment since 1908. The rotation until 1912 was (1) corn followed by a cover crop of rye and vetch, (2) oats, (3) wheat, and (4) clover and timothy. Soybeans have displaced oats in the rotation since 1912. The soil was a sassafras silt loam on which 1,500 pounds of hydrated lime were applied to one-half of each plat before corn planting.

The percentages were corrected for soil heterogeneity according to the following formula $CY = AY - N + NW$.[3] The corrected percentages were then analyzed and the odds in favor of their significance determined by the modification of Student's method as given by Love.[4]

It will be seen from a study of Table 1 that fertilizers have caused no significant difference in the percentage of protein in soybeans.

The oil content of the soybeans was changed by the action of fertilizers (Table 2). Single elements did not affect the composition, but when applied in combination they did. Nitrogen and phosphorus caused a very significant decrease in the oil content when applied on unlimed soil. Phosphorus and potassium in combination, as well as nitrogen and potassium, caused a decrease in the oil content upon the unlimed soil. A complete chemical fertilizer had no significant effect on the oil content upon either limed or unlimed soil. Manure, however, caused a small significant loss in oil.

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[1] Contribution from the Department of Agronomy, Delaware Agricultural Experiment Station, Newark, Del. Received for publication March 8, 1927.

[2] Agronomist and Assistant Agronomist, respectively.

[3] Schuster, G. L. Fifteen years of field experiments with manure, fertilizers, and lime. Del. Agr. Exp. Sta. Bul. 137. 1924.

[4] Love, H. H. A modification of Student's table for use in interpreting experimented results. Jour. Amer. Soc. Agron., 16:68–73. 1924.

TABLE 1.—*Showing average increase or decrease in percentage of protein in soybeans from different fertilized plats, 1921, 1924, and 1925.*[a]

Treatment, pounds per acre	Limed Protein %	Limed Odds	Unlimed Protein %	Unlimed Odds
Nitrate of soda, 100	2.18	1:2.62	—0.72	1:7.63
Acid phosphate, 250	1.89	1:3.69	—1.72	1:10.9
Muriate of potash, 75	—3.87	1:6.69	—2.81	1:23.1
Nitrate of soda, 100 Acid phosphate, 250	—0.94	1:5.83	—0.51	1:1.35
Acid phosphate, 250 Muriate of potash, 75	—4.97	1:5.83	—2.82	1:3.99
Nitrate of soda, 100 Muriate of potash, 75	—3.55	1:3.69	—4.04	1:10.9
Nitrate of soda, 100 Acid phosphate, 250 Muriate of potash, 75	—1.86	1:3.69	—2.08	1:3.39
Manure, 5,000	—0.64	1:2.39	—3.29	1:4.33

[a]The no fertilizer plats gave 41.93% protein with lime and 40.6% without lime.

TABLE 2.—*Showing average increase or decrease in percentage of oil in soybeans from different fertilized plats, 1921, 1924, and 1925.*[a]

Treatment, pounds per acre	Limed Oil %	Limed Odds	Unlimed Oil %	Unlimed Odds
Nitrate of soda, 100	0.67	1:3.12	—0.27	1:2.18
Acid phosphate, 250	—1.24	1:3.69	—0.34	1:4.33
Muriate of potash, 75	0.63	1:3.12	—0.21	1:3.99
Nitrate of soda, 100 Acid phosphate, 250	0.27	1:3.69	—1.34	1:2499
Acid phosphate, 250 Muriate of potash, 75	0.17	1:1.35	—0.71	1:122
Nitrate of soda, 100 Muriate of potash, 75	0.96	1:21.3	—0.47	1:369
Nitrate of soda, 100 Acid phosphate, 250 Muriate of potash, 75	1.16	1:5.83	—0.50	1:2.18
Manure, 5,000	—0.79	1:6.69	—0.76	1:66.1

[a]The no fertilizer plats gave 16.5% oil with lime and 17.52% without lime.

TABLE 3.—*Showing average increase or decrease in protein and oil content of soybeans due to lime with various fertilizers, 1921, 1924, and 1925.*

Treatment, pounds per acre	Oil Gain for lime	 Odds	Protein Gain for lime	 Odds
	%		%	
No fertilizer . . .	—0.98	1:51.1	1.33	1:7.63
Nitrate of soda, 100.	—0.11	1:1.22	4.24	1:3.69
Acid phosphate, 250	—1.75	1:7.63	4.97	1:7.63
Muriate of potash, 75.	—0.07	1:1	0.11	1:1.81
Nitrate of soda, 100. Acid phosphate, 250	0.69	1:2.62	0.92	1:1.81
Acid phosphate, 250. Muriate of potash, 75	0.11	1:1.22	—0.47	1:1
Nitrate of soda, 100 Muriate of potash, 75	0.45	1.6.69	1.83	1:2.18
Nitrate of soda, 100 Acid phosphate, 250 Muriate of potash, 75	0.68	1:1.49	1.68	1:2.62
Manure, 5,000.	0.04	1:1	3.64	1:3.69

A study of Table 3 shows that the only significant change obtained in the composition was as a result of liming the unfertilized plats where the oil content was decreased. The oil content of the beans on the fertilized plats was not materially changed by liming.

These results, as well as the results of other investigators, indicate that the composition of the soybean cannot be changed by soil treatments. One must look to genetics, therefore, for any improvement in soybeans as to oil and protein content. Grantham,[5] in his varietal studies, found a range of 9.4% protein and 6.3% oil which suggests a possible basis for the improvement of the soybean.

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[5] GRANTHAM, A. E. Soybeans. Del. Agr. Exp. Sta. Bul. 96. 1912.

PRODUCTION OF ARTIFICIAL FARMYARD MANURE BY FERMENTING STRAW[1]

W. V. Halversen and E. F. Torgerson[2]

The production of artificial farmyard manure by decomposition of straw has attracted much attention in recent years. In certain sections it has been a common practice to burn the straw either as stubble or in the stack. To those interested in soil conservation, this practice of destroying organic matter by fire seems appalling, especially since those sections practicing such destructive methods are usually the ones that need the organic matter for its water-holding capacity and its value in maintaining the physical condition of the soil.

The harmful practice of burning straw cannot be stopped without showing an economical way whereby the straw can be utilized to advantage. The farmer and the market gardener in many sections have known for many years that plowing under large quantities of straw means losses through decreased yields during the following years. Investigators in several states have studied the detrimental effects of plowing under straw to ascertain the reasons for the decreased yields and possible means of overcoming it.

A discussion of the literature pertaining to this subject was presented recently by Collison and Conn[3] who made studies on the nature of the toxic properties of straw and concluded that, "Two separate harmful factors are associated with straw and other plant residues. First, a toxic chemical agent which acts upon the plant immediately after germination, although not having a very pronounced effect in the presence of much colloidal matter, as in clay soils. Second, a biological factor due to the stimulation of microorganisms which compete with plants for their nitrogen. This second factor has been recognized by most of the previous writers on the subject."

Historically, attention to the possibility of overcoming these toxic effects by producing artificial farmyard manure was stimulated

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[1] Contribution from the Departments of Bacteriology and Soils, Oregon Agricultural Experiment Station, Corvallis, Ore. Received for publication March 12, 1927.

[2] Associate Bacteriologist and Assistant in Soils, repsectively. The authors take this opportunity to thank Dr. W. L. Powers, Prof. G. V. Copson, and Prof. G. R. Hyslop for the many courtesies and suggestions extended during the execution of this work.

[3] Collison, R. C., and Conn, H. J. The effect of straw on plant growth. N. Y. State Agr. Exp. Sta. Tech. Bul. 114. 1925.

by the appearance of a report of some investigations by Hutchinson and Richards[4] of the Rothamstead Experiment Station in which they outlined the essential conditions for the production of artificial farmyard manure. The process required air, suitable temperature, a supply of soluble nitrogen compounds in suitable concentration, and a neutral or slightly alkaline reaction. They studied many sources of nitrogen and concluded that ammonium sulfate was unsatisfactory because it left the medium acid but recommended that the nitrogen be added in the form of urea, urine, ammonium carbonate, or peptone. They found that mass inoculation of the straw with faeces or other material did not stimulate decomposition. On studying the necessary amount of nitrogen to add to the straw, they concluded that 0.7 to 0.75 parts of nitrogen to every 100 parts of dry straw gave the best results.

So great has been the demand for information concerning this process that popular magazines have made feature stories of it and farmers and trucksters have requested information on methods of making this compost. Several commercial companies have met the demands by putting patented materials on the market under various trade names. In order to meet the demand for information, a number of experiments have been carried out at the Oregon Experiment Station, a preliminary report of which is herewith presented. Upon analyzing the problem, it was deemed advisable to test the possibilities by performing a number of preliminary experiments to decide upon the relative value of several accessible forms of nitrogen and to check further on the most economical amounts to apply. These experiments were run by filling Mason fruit jars with a given quantity of straw and treating with the various nitrogen fertilizers, adding moisture, plugging the jar with cotton, and incubating at 37°C in the laboratory. It cannot be expected that results secured in the laboratory in this manner can represent practical field conditions. This method of procedure, however, does give a good opportunity to observe the various phases of decay.

In these preliminary tests it was found that ammonium sulfate in the presence of sufficient lime to neutralize the sulfuric acid left after the ammonia had been used in the fermentation process gave results consistently superior to sodium nitrate, ammonium phosphate, and diluted urine. Since ammonium sulfate is readily accessible and ground limestone is accessible and comparatively cheap, an experiment was planned to determine the most economical amount to stimulate the decay process.

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[4] HUTCHINSON, H. B., AND RICHARDS, E. H. Artificial farmyard manure. Jour. Min. Agr. Great Britain, 28:398-411. 1921.

TABLE 1.—*Study of decomposition of straw in production of artificial manure.*

Treatment	Test No.	Pounds of liquid drained off after 6 months	Pounds of wet straw in tank after fermentation	Equivalent weight dry straw in tank, pounds	Pounds of dry straw remaining in tanks, average	Pounds lost	Loss of dry straw, %
None	1	4.93	47.32	12.66	13.60	6.40	32.0
	2	4.54	44.71	14.54			
Lime, 100 pounds per ton	3	4.93	49.07	11.95	11.23	8.77	43.8
	4	1.10	59.15	10.52			
0.25% N and 100 pounds lime per ton	5	2.01	47.99	10.17	9.40	10.60	53.0
	6	3.16	52.59	8.64			
0.50% N and 100 pounds lime per ton	7	5.54	46.71	9.11	9.34	10.66	53.3
	8	6.16	47.09	9.58			
0.75% N and 100 pounds lime per ton	9	5.63	47.62	8.99	9.16	10.84	54.2
	10	7.98	44.77	9.34			
1% N and 100 pounds lime per ton	11	4.83	49.07	9.82	10.41	9.59	47.9
	12	7.12	48.63	11.00			
3% N and 100 pounds lime per ton	13	4.50	51.50	11.95	11.65	8.35	41.7
	14	10.94	46.06	11.35			
Liquid infusion of rotted manure	15	6.88	48.22	10.29	10.40	9.60	48.0
	16	5.63	48.77	10.52			

The experiment was carried out as outlined in Table 1, using large galvanized iron tanks as receptacles. Duplicate tanks were made in order to check each treatment.

The experiment was started on March 14 and was incubated out of doors for about six and one-half months.

Twenty pounds of dry wheat straw were placed in each tank and the amendments were added with enough water to saturate the straw. The straw absorbed nearly five times its weight of water. Lime was added in each case at the rate of 100 pounds per ton of dry straw, except in the case of Nos. 15 and 16 where no lime was added. In this case, an infusion of well-rotted manure was made by diluting the manure with four times its weight of water and this infusion was used to saturate the straw. Water was added occasionally to maintain saturation. The temperature was recorded occasionally, the averages being given in Table 2. At the end of the experiment the H-ion concentration and the moisture content were determined.

TABLE 2.—*Average temperature, reaction, and moisture content of fermented straw.*

Test No.	Average temperature, C	pH	Moisture, dry basis %
1	20.82°	8.521	274
2	20.96°	7.929	225
3	20.53°	8.605	296
4	20.53°	8.690	349
5	21.41°	8.267	365
6	21.04°	8.351	448
7	21.25°	6.323	432
8	21.66°	5.985	394
9	22.08°	6.914	452
10	21.89°	6.238	406
11	21.95°	7.506	382
12	21.08°	6.492	330
13	20.54°	7.506	296
14	20.79°	7 168	316
15	20.00°	7.506	360
16	20.90°	6.745	349

The data in Table 1 showed that a vigorous decomposition took place during the incubation period and that the greatest amount of decay occurred where 0.75% nitrogen was added. This amount was only slightly better than 0.5% nitrogen which in turn was only slightly better than 0.25% nitrogen. One per cent nitrogen was not conducive to rapid decay. If similar data had been obtained at the end of three months, it is probable that greater individual differences would have been apparent, but purposely the fermentations were permitted to continue until the straw was actually reduced to humus. The state of decomposition can best be judged from Figs.

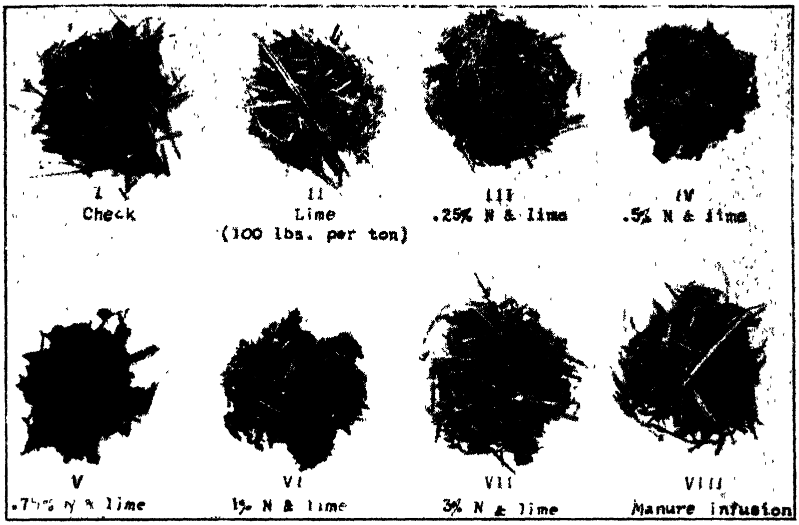

FIG. 1.—State of decay of composts after six and a half months incubation.

1 and 2. It is obvious that 0.5% N and 0.75% N were both satisfactory. This would warrant the recommendation of the smaller amount in the interest of economy.

At the Rothamstead Station an increase in temperature during fermentation was observed which favored the rate of decay. In this experiment the bulk of straw was so small that the temperature remained low and consequently the rate of decay was slow.

The H-ion concentration reported was determined electrometrically on some of the excess moisture which was drained off the bottom of the tank. Here it will be observed that a slight amount of acidity did accumulate in the best fermentations. This is an indication of lack of available base to keep the fermentation alkaline. It is possible

FIG. 2.—Amount of straw left in the tanks after six and a half months incubation. From left to right: Check; lime, 100 pounds per ton; lime and 0.25% N; lime and 0.5% N; lime and 0.75% N; lime and 1% N; lime and 3% N; manure infusion.

that decomposition would have taken place more rapidly if more lime had been used. The nitrogen economy of the process is of immense importance.

TABLE 3.—*Nitrogen economy of the process.*

Test No.	Grams of N added as $(NH)_2SO_4$	Grams of N in straw at beginning	Total N in straw plus amendment in grams	Actual amount of N present at end of test, grams	N loss or gain in grams during fermentation
1	——	24.05	24.05	21.59	— 2.46
2	——	24.05	24.05	26.52	+ 2.45
3	——	24.05	24.05	18.89	— 5.16
4	——	24.05	24.05	18.59	— 5.46
5	22.68	24.05	46.73	40.38	— 6.35
6	22.58	24.05	46.73	39.12	— 8.61
7	45.36	24.05	69.41	55.67	—13.74
8	45.36	24.05	69.41	53.96	—15.45
9	68.04	24.05	92.09	61.57	—30.52
10	68.04	24.05	92.09	61.73	—30.36
11	90.72	24.05	114.77	71.12	—43.65
12	90.72	24.05	114.77	67.51	—47.26
13	272.16	24.06	296.22	226.96	—69.26
14	272.16	24.05	296.22	216.35	—79.87
15	liquid manure infusion	24.05	——	22.28	— 1.77[a]
16	liquid manure infusion	24.05	——	23.62	— 0.43

[a] Nitrogen content of infusion was not determined.

In comparison with these results Hutchinson and Richards concluded that (a) straw overloaded with nitrogen loses it to a definite degree; that (b) straw with the requisite amount of nitrogen may undergo rotting without appreciable loss and is therefore in a state of equilibrium; and that (c) undersaturated straw, by the agency of micro-organisms, exhibits a well-marked property of picking up nitrogen, particularly in the form of ammonia, until the same final content of nitrogen in the rotted product is attained.

Table 3 shows a loss of nitrogen in every case except the check. These results do not entirely justify the above postulates of Hutchinson and Richards, because here a loss of nitrogen actually occurred in all cases except the check. On the other hand, they encountered an increase in nitrogen content of undersaturated composts which they attributed to fixation of ammonia, but they do not explain where the ammonia came from. Loss of nitrogen in this experiment probably takes place where a small layer of straw on the surface becomes dry and the ammonia volatilizes. Since the greatest nitrogen losses occur where the most nitrogen is added, these data would lead to the conclusion that the smallest application which will stimulate decay would be the most economical amount to apply.

These data bear out the general observations of Hutchinson and Richards that during the process of fermentation of plant residues having a wide carbon-nitrogen ratio the loss of carbonaceous material through the evolution of carbon di-oxide causes a narrowing of the ratio. The greatest increase in the percentage of nitrogen of the decaying material will be found where the greatest amount of decay takes place. Under the conditions of this experiment this increase in the percentage of nitrogen in the compost takes place in the presence of an actual loss of nitrogen. There is obviously a discrepancy in the case where 3.0% nitrogen was used which cannot be accounted for in the light of our other data. Experiments are now in progress in this laboratory with the view of adjusting the straw as a culture medium with the hope that it may support a vigorous flora of nitrogen-fixing organisms.

TABLE 4.—*Effect of fermentation on percentage of nitrogen.*

Treatment	N in straw	N after fermentation	Increase in N during fermentation
	%	%	%
None	0.265	0.389	0.124
100 pounds lime per ton	0.265	0.368	0.103
0.25% N+lime	0.265	0.936	0.421
0.50% N+lime	0.265	1.293	0.527
0.75% N+lime	0.265	1.526	0.411
1% N+lime	0.265	1.474	0.209
3% N+lime	0.265	4.194	0.929
Manure infusion	0.265	0.487	0.222

The process of decay apparently progresses in two distinct phases. First, molds and several types of fleshy fungi grow luxuriantly. The straw becomes yellow and the temperature rises. This is followed by a second phase which is characterized by a dark brown color and a receding of the temperature. During this second phase large numbers of bacteria accummulate. Attempts at accelerating decomposition by using enrichments of decay organisms from successive fermentations have generally given no better results than spontaneous fermentation.

The cost of this process can be estimated from the following figures. Take, for example, the 0.5% N application which gave very favorable results. This amount of nitrogen would be equivalent to 47.6 pounds of ammonium sulfate per ton of dry straw and would cost approximately $2.06. The lime would cost in Oregon about $.32

per 100 pounds, making a total cost of $2.38 for treating 1 ton of dry straw. This amount of dry straw will soak up five times its weight of water, making 6 tons of wet straw. The fermentation would cause a loss of approximately 50% of the dry matter, leaving about 3 tons of well-rotted wet manure, with a cost of approximately 80 cents per ton. It is possible that subsequent studies may show that an application of less than 0.5% nitrogen may be practicable where a longer period of fermentation is possible or desirable.

It is quite possible that farmers in general will not use this process, but it does offer big possibilities to the market gardener. The straw should be soaked with water and treated as the stack is being made, because it is very hard to soak a stack after it settles, as it sheds the water about the edges leaving an unfermented shell or border around the outside of the stack. If composting is done during the summer time, it will be necessary to add water occasionally. This can be done satisfactorily by using a garden sprinkler. Under conditions where water is not available to the straw stack, it is often advantageous to put an eaves trough on the barn or other buildings and drain the water off onto the straw stack. The rainfall in the Willamette Valley is sufficient to soak through only about 3 feet of loose straw. In stacking straw for this purpose the stack should be made level so as not to shed rain either outward or toward the center.

That this amount of nitrogen will stimulate rapid decomposition when applied to a straw stack has been demonstrated at the Oregon Experiment Station. A barley straw stack containing 3 tons of straw was treated by mixing 47.5 pounds of ammonium sulfate and 100 pounds of ground limestone per ton with the straw at the time of threshing. Water was sprayed on the stack from a garden hose until the straw was saturated. Decomposition began at once and the trial was a success.

Attempts to determine the state of decomposition by the tensile strength of the straw have been made at different periods of fermentation to see if any correlation exists between the stage of the decay process and the tensile strength of the straw. Variations in the individual straws and their moisture content make these results so variable that it is impossible to determine the stage of decay from the tensile strength of the fermenting straw with any degree of accuracy.

INFLUENCE OF BORDER ROWS IN VARIETY TESTS OF SMALL GRAINS[1]

H. W. HULBERT AND J. D. REMSBERG[2]

INTRODUCTION

It is commonly recognized by agronomists that border rows of experimental plats and competition between varieties are sources of considerable error. The effect of border rows is particularly noticeable in the semi-arid and non-irrigated areas of the West where soil moisture is usually the limiting factor in crop production. A great majority of the previous investigations upon this problem have been conducted in the more humid sections of the United States and the resulting recommendations are not entirely applicable to western conditions.

Barber (1)[3] found that rows bordering pathways produced more grain and straw and were later in maturity than interior rows. He assumed that an area 6 inches wide around the plat received benefit from the cultivated pathways. Stadler (3) and Kiesselbach (4, 5) found that competition between dissimilar crops for moisture, nutrients, and possibly light resulted in error in crop tests. Cole and Hallstead (2), investigating with kafir and milo, obtained very marked increase in yield from the outside rows. The excess yield of grain was roughly proportionate to the increased available soil area.

The work reported in this paper was designed to furnish more definite information concerning the reduction of error in experimental work due to border effect.

EXPERIMENTAL METHODS

Investigations were conducted on variety tests of winter and spring wheat, barley, and oats, and on rate and date of seeding trials of winter and spring wheat.

The plats used were 7 feet in width and 155.56 feet in length, or one-fourtieth of an acre in area. An alley 2 feet in width separated each plat. The plats were arranged side by side in series according to each cereal group. The alleys between the plats and the roadways at either end were cultivated twice during the growing season to prevent weed growth. A 7-foot 14-row Superior drill, which had been calibrated and found to deliver very uniform quantities of seed in each row, was used in seeding the plats. The actual delivery in each drill row is given in ounces per row in Fig. 1. The rows in each plat were numbered 1 to 14, respectively. Rows 1 and 14 were taken as the outside and 2 and 13 as the inside border rows.

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[1] Contribution from the Department of Agronomy, Idaho Agricultural Experiment Station, Moscow, Ida. Idaho Technical Paper No. 48. Received for publication April 5, 1927.

[2] Agronomist and Assistant Agronomist, respectively.

[3] Reference by number is to "Literature Cited," p. 589.

The border rows were harvested by hand. Bundles from each row were tagged and numbered according to row, plat, and variety and were shocked separately. The 10 interior rows were harvested with a grain binder and the bundles shocked together.

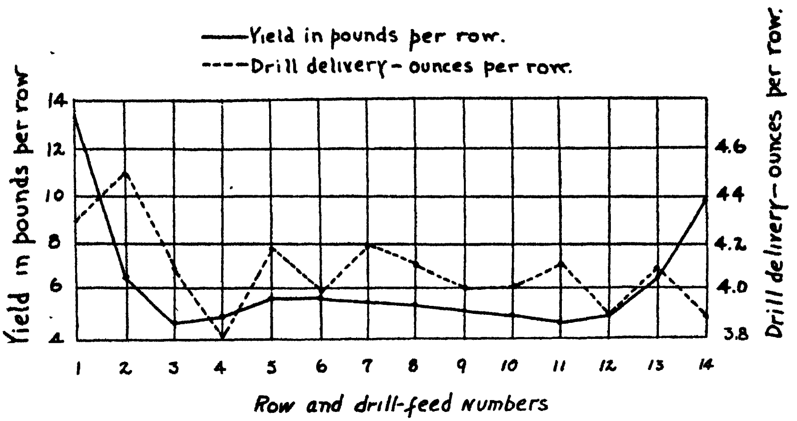

FIG. 1.—Yields and delivery rates of individual drill-rows of White Odessa wheat.

Bundles from each of the border rows and from the 10 interior rows were weighed just previous to threshing in order that correlation between increased straw production and yield of grain, due to border effect, might be determined. The grain was threshed with a No. 3 Ellis-Keystone separator which was especially equipped for thorough cleaning. Each of the border rows was threshed separately and weights were taken of the yield.

EXPERIMENTAL RESULTS

Observation on the plats during the jointing, heading, and maturation periods showed that additional growth occurred in the two rows bordering the cultivated alleys. The 10 interior rows did not display a noticeable variation in development. In order to determine the extent to which border effect occurred, a representative plat of White Odessa wheat was harvested in individual rows. The additional yield due to increased available area was found to extend only through the inside border row. These results are shown in Fig. 1, together with the actual amount of seed delivered per row in planting. The maximum variation in the amount of seed delivered per row was 0.7 ounce which produced no correlated variation in the yield per row.

A material increase in yield was obtained in variety and rate and date of seeding tests when border rows were included in the calculations. The error which results from such calculations places the experimental yield of all varieties above their true yielding ability. Table 1 shows the increase in yield of all varieties which results when the inside and outside border rows are included in the calculation of yields. The yield of the 10 interior rows were taken as 100%, or the true yielding ability of the varieties. Removal of the outside border rows eliminated a considerable portion of the error due to border effect. However, a marked increase in yield was displayed when rows 2 and 13 were included. Therefore, in order to remove more completely the error due to border effect, it was necessary to remove two border rows from each side of the plat.

TABLE 1.—*Showing the effect of removal of border rows upon yield and percentage yield of small grains, Moscow, 1925–26, inclusive.*

Crop	Number of varieties	2-year average acre yields Rows 3–12	 Rows 2–13	 Entire plat
Barley	10	70.4 bu.	81.0 bu.	100.6 bu.
		100%	114.5%	142.9%
Oats	21	61.6 bu.	67.3 bu.	81.9 bu.
		100%	109.3%	132.9%
Spring wheat	17	40.4 bu.	41.9 bu.	48.3 bu.
		100%	103.7%	119.6%
Winter wheat, rate and date.	14 plats	59.0 bu.	67.9 bu.	85.9 bu.
		100%	115.1%	155.6%

An analysis of data taken on rate and date of seeding spring and winter wheat showed that the amount of border effect is influenced by rate of planting. A summary of these data is given in Table 2. Plats of Federation, Red Bobs, and Jenkin replicated three times were used for information on spring wheat, while Triplet, Mosida, and Ridit replicated twice were used for winter wheat information.

Assuming that yields obtained from the 10 interior rows represent the true yield of the plat, considerable error results when the border rows are included in the calculation of plat yields. Such was the case when it was found that the amount of increase and consequently the error due to border effect varied according to the rate of seeding. The last two columns in Table 2 show the amount of increase in bushels per acre and the percentage increase in yield due to border effect. Increased plant competition in the heavier seedings resulted in a more complete utilization of the soil moisture and plant food materials in the alleys. When the net yield of each rate of seeding was calculated on the basis of the entire plat instead of on the 10 interior rows, the order or ranking was changed. The lightest rate of seeding in both winter and spring wheat gave the greatest net yield. Recommendations based on these data would be incorrect should the entire plat yields be taken as the basis for comparison.

TABLE 2.—*Showing differential border effect in rate of planting spring and winter wheat.*

Rate of seeding in pecks	Row 1	Row 2	Rows 3–12 Gross	Rows 3–12 Net	Row 13	Row 14	Entire plat Gross	Entire plat Net	Amount increase	Percentage increase
					Spring Wheat					
3	93.6	55.7	46.9	46.1	57.3	90.6	54.4	52.6	7.5	15.99
5	101.3	54.4	46.8	45.5	57.9	95.3	54.9	53.6	8.1	17.30
7	98.8	53.2	44.6	42.8	55.7	99.6	53.7	51.9	9.1	20.40
					Winter Wheat					
4	115.7	78.7	64.9	63.9	80.1	106.5	70.7	69.7	5.8	8.93
6	126.2	79.5	61.8	60.3	80.1	124.1	73.2	71.7	11.4	18.44
8	138.2	79.7	58.9	56.9	79.3	128.5	72.6	70.6	13.7	23.26

The correction of data for error due to border effect has greater significance when the rank in yielding ability of a number of varieties is changed. A summary of data taken over a period of 10 years on six principal spring wheat varieties is shown in Table 3. The rank of these varieties based on yields of entire plats was found to be erroneous when 10 interior rows of each plat were used as the basis for calculation of yield. According to field observations, Baart was found to be the outstanding variety in vigor of plant growth. This variety ranked third among the six under observation and for several years was recommended accordingly. However, when the error due to border effect was corrected Baart ranked lowest. A

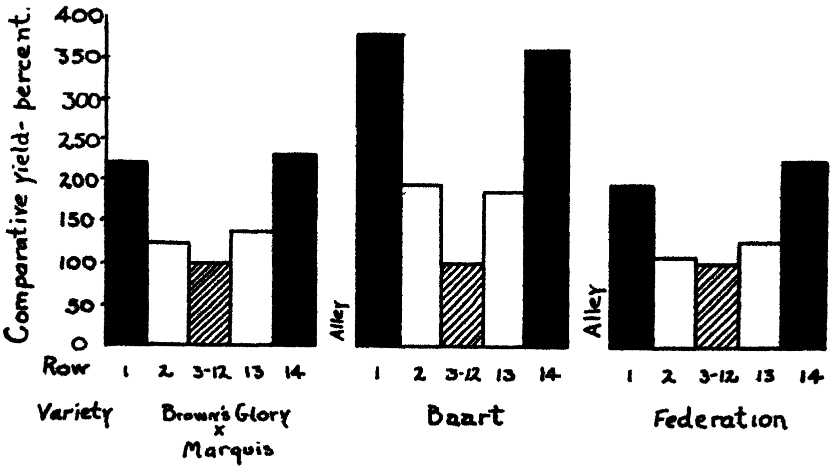

FIG. 2.—Comparative yields of border rows of Baart and adjoining varieties.

graphical representation of the extent to which Baart utilized the additional space afforded by the alleys is shown in Fig. 2. In this illustration the yield of each of the varieties is taken as 100% in order to display on a uniform basis the manner in which border rows augment the plat yield of Baart to a greater extent than its neighboring varieties.

TABLE 3.—*Showing the 10-year average yields of spring wheat obtained from harvesting entire plats, together with their yields corrected for border effect, Moscow.*

Variety	10-year average yields in bushels per acre entire plat	1925–26 percentage yield based on rows 3–12 as 100%	Corrected yield[a]	Rank Entire plat	Rank Corrected yield
Jenkin.....	39.0	122.9	31.7	1	1
Little Club.	36.6	120.1	30.4	2	2
Baart.....	36.3	135.9	26.7	3	5
Bluestem...	35.6	122.8	28.9	4	4
Marquis...	34.5	115.7	29.8	5	3
Defiance. .	34.0	118.3	28.7	6	5

[a] Corrected yield determined by formula: Average yield : x :: per cent yield of entire plat : 100. Example: Jenkin 39.0 : x :: 122.9 : 100. x=31.7.

CONCLUSIONS

1. Experimental yields are greatly augmented when border rows are included with the plat. In this connection it is assumed and has been demonstrated that the yield calculated with the exclusion of two border rows on each side of the plat more nearly represents the true plat yield.

2. The varieties or cultural methods under investigation should be ranked correctly according to their yielding abilities.

3. The rank as well as actual yields of varieties or cultural methods may be incorrect when border rows are included in the calculation of plat yields.

4. The removal of or correction for border rows in experimental work therefore becomes a necessity under western conditions.

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RELATION OF ENDOSPERM CHARACTER IN CORN TO ABSORPTION OF HYGROSCOPIC MOISTURE[1]

H. W. ALBERTS[2]

Endosperm character is one of the factors which determine the rate and amount of moisture absorbed by the corn kernel. Various investigators have given considerable attention to endosperm character. The terms "starchy" and "horny", although not altogether satisfactory, have been largely used in the literature to denote two contrasting conditions of endosperm. Starchy endosperm is described by Trost (9)[3] as that portion of the endosperm which appears opaque when the kernel is held up to the light, while the portion containing horny endosperm is more or less translucent. In accordance with the proposal by Dungan (4), the term "floury" is adopted in the present paper to denote that condition of endosperm in which the material is largely of a soft or mealy consistency.

Haberlandt (5) stated that, where the starch grains are crowded together, they tend to assume polyhedral shapes as a result of mutual interference, whereas, in the mealy portions, rounded grains predominate. The shape of the starch grains as they appear in a photomicrograph is illustrated by Weatherwax (10), who, like Haberlandt, found that the starch grains in the horny endosperm are closer together and more compact than those of the starchy endosperm. A chemical analysis reported by Weatherwax showed that starchy endosperm was higher in protein than horny endosperm. This, however, is not in accord with the conclusion reached by Hopkins, et al (6), who found that the "horny starch" was richer in protein than the "white starch," and that the "horny gluten," the portion immediately beneath the hull, was richest in protein of all parts of the corn kernel.

It has been found that corn which has a floury endosperm absorbs water in larger amount and at a faster rate than corn which has a horny endosperm. Biggar (2) placed 100 grams of each of three different types of corn between wet bleached muslin and weighed them after 22 hours. Blue flour corn absorbed 18.0% water, Reid Yellow Dent 13.5%, and flint corn only 6.6%. Dungan (3) used the amount of water absorbed by the grain as a measure of the degree of "starchiness" or "horniness" of the kernel.

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[1] Contribution from the Departments of Botany and Agronomy, University of Illinois, Urbana, Ill., published with the approval of the Director of the Agricultural Experiment Station. Received for publication April 5, 1927.

[2] Director of the Alaska Agricultural Experiment Stations, U. S. Department of Agriculture, Sitka, Alaska.

[3] Reference by number is to "Literature Cited," p. 595.

Bailey and Gurjar(1) stated that moisture in wheat may be assumed to exist as imbibed water in loose combination with organic colloids which form elastic gels. Sargant and Robertson (7) found that in germination the horny endosperm was dissolved by degrees, while the floury endosperm in the grasses studied became semi-fluid as soon as germination began. Shull (8) stated that the main chemical changes with rise of temperature are believed to occur in the colloids of the seed and not in the semi-permeable seed coat. Semi-permeability, as such, is thought not to be an important factor in determining the rate of absorption.

The results brought out by some of the investigations mentioned above show that floury corn absorbs more moisture than horny corn if the kernels are soaked in water or placed in direct contact with moisture. The object of the investigation reported in this paper was to determine the relation of floury and horny endosperm to absorption of hygroscopic moisture.

MATERIALS AND METHODS

The corn used for this test was a strain of Reid Yellow Dent grown in the fields of the experiment station at Urbana, Illinois. Two sets of ears differing as widely as possible in flouriness and horniness were selected on November 5, 1924, and were stored in the laboratory until January 24, 1925, when the test was started. The corn at this time contained approximately 10% moisture (total weight basis). The floury kernels were apparently more than three-fourths floury and the horny kernels had only a small band of floury endosperm at the crown.

Two 110-gram samples of shelled corn of each type were used. One sample of each type was suspended in a wire basket over 250 cc of water in a sealed jar and the other over 250 cc of concentrated sulfuric acid. The temperature was kept constant at 30°C in a controlled temperature case in the Plant Physiology Laboratory. The samples were weighed at 3-day intervals and were then exchanged as to jars, i. e., those suspended above water were placed over sulfuric acid and vice versa. This exchange at 3-day intervals was continued for a period of 45 days. The percentage deviations in weight from the original samples were then calculated. The results are shown in Table 1 and illustrated graphically in Fig. 1.

It will be noted that with the exception of the two lots of corn which were suspended over sulfuric acid for the first 3-day interval, the weight of the different lots of corn never fell below the weights which they had at the beginning of the experiment. Sometimes,

TABLE 1.—*Percentage deviation from original weight of corn.*

Lot No.	Character of endosperm	Deviation from original weight at end of 3 days %	6 days %	9 days %	12 days %	15 days %	18 days %	21 days %	24 days %
1	Starchy	−1.6[a]	11.5	0.2	11.4	0.9	10.7	0	10.1
2	Horny	−0.9	9.2	1.4	10.3	1.5	10.3	1.4	10.3
3	Starchy	9.9	0	11.6	0	10.2	0.5	10.4	0.1
4	Horny	8.8	1.4	10.2	1.4	10.2	1.7	10.4	1.5
			27 days %	30 days %	33 days %	36 days %	39 days %	42 days %	45 days %
1	Starchy		0.2	10.1	0.2	10.2	0.3	9.8	0.9
2	Horny		1.5	11.2	1.7	10.0	1.5	9.5	1.2
3	Starchy		10.1	0.2	9.8	0.1	9.6	0.3	10.5
4	Horny		10.6	1.5	9.5	1.2	9.4	1.5	10.3

[a]Weight of corn was less than original weight at the end of the 3-day interva

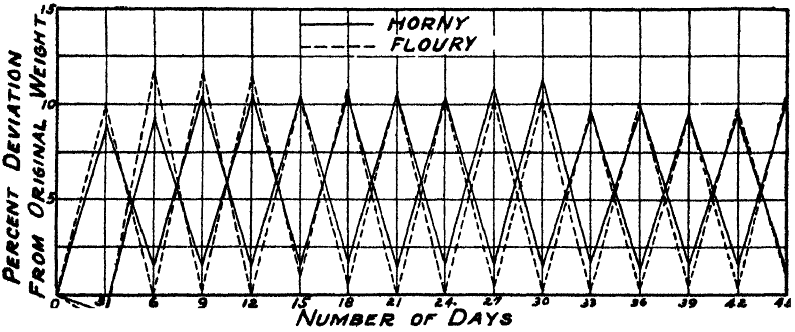

FIG. 1.—Comparison of floury and horny corn in rapidity of absorption and release of moisture. The graphs show the percentage of moisture above or below the original weight at the end of each 3-day period.

however, the weight of the corn which had been suspended above water and was then suspended over acid approached the original weight as is shown in Fig. 1.

For the first 12-day period the percentage increase in weight of floury corn for each 3-day period over water was greater than that for horny corn. During this same period the reduction in weight, after the corn had been suspended above acid for 3-day periods, was also greater for the floury corn. After the first 12 days the maximum percentage increase in weight of the horny corn was approximately the same as that of the floury corn, except on the 27th and 30th days. During this same period the minimum percentages of moisture in floury corn for each of the 3-day intervals over acid were below those in horny corn.

The average maximum percentage increase in weight of corn suspended above water was 0.5 greater for floury corn than for horny corn as is shown in Table 2.

TABLE 2.—*Maximum percentages above original weight of corn which had been suspended over water for 3-day periods.*

Length of time from beginning of experiment, days	Percentage above original weight Floury corn (Lot No. 3)	Percentage above original weight Horny corn (Lot No. 4)	Percentage difference (Floury-Horny)
3	9.9	8.8	1.1
6	11.5	9.2	2.3
9	11.6	10.2	1.4
12	11.4	10.3	1.1
15	10.2	10.2	0
18	10.7	10.3	0.4
21	10.4	10.4	0
24	10.1	10.3	—0.2
27	10.1	10.6	—0.5
30	10.1	11.2	—1.1
33	9.8	9.5	0.3
36	10.2	10.0	0.2
39	9.6	9.4	0.2
42	9.8	9.5	0.3
45	10.5	10.3	0.2
Average difference			0.5

When the different lots of corn were placed over acid for 3-day periods, their weights were reduced so that they weighed only a little more than the original samples. The average percentage reduction in weight was greater for the floury corn than for horny corn. Table 3 shows the minimum percentage above the original weight of corn which had been suspended over acid for a 3-day period prior to which it had been suspended over water for the same length of time. The table shows also the differences of the percentages above original weight between the floury and the horny corn. It was found that the average difference was 1.1%, showing that the minimum weight of floury corn was less than that of horny corn.

A further study was made to compare floury and horny corn in total change of weight from one period to the next. For example, the maximum percentage above original weight for floury corn in Lot 1 on the 24th day after the beginning of the experiment was 10.1 and on the 27th day the minimum percentage above original weight was 0.2. a difference of 9.9. The maximum percentage above original weight for the horny corn in Lot 2 on the 24th day after the beginning of the experiment was 10.3 and on the 27th day the minimum percentage above original weight was 1.5, or a difference of 8.8 as shown in Table 4.

TABLE 3.—*Minimum percentages above original weight of corn which had been suspended over acid for 3-day periods.*

Length of time from beginning of experiment, days	Percentage above original weight Floury corn (Lot No. 1)	Percentage above original weight Horny corn (Lot No. 2)	Percentage difference (Horny-Floury)
3	—1.6[a]	—0.9[a]	0.7
6	0	1.4	1.4
9	0.2	1.4	1.2
12	0	1.4	1.4
15	0.9	1.5	0.6
18	0.5	1.7	1.2
21	0	1.4	1.4
24	0.1	1.5	1.4
27	0.2	1.5	1.3
30	0.2	1.5	1.3
33	0.2	1.7	1.5
36	0.1	1.2	1.1
39	0.3	1.5	1.2
42	0.3	1.5	1.2
45	0.9	1.2	0.3
Average difference			1.1

[a] Below original weight.

TABLE 4.—*Total periodic change in weight.*

Length of time from beginning of experiment, days	Percentage differences Floury corn (Lot No. 1)	Horny corn (Lot No. 2)	Floury corn (Lot No. 3)	Horny corn (Lot No. 4)
3	1.6	0.9	9.9	8.8
6	13.1	10.1	9.9	7.4
9	11.3	7.8	11.6	8.8
12	11.2	8.9	11.6	8.8
15	10.5	8.9	10.2	8.8
18	9.8	8.8	9.7	8.5
21	10.7	8.9	9.9	8.7
24	10.1	8.9	10.3	8.9
27	9.9	8.8	10.0	9.1
30	9.9	9.7	9.9	9.1
33	9.9	9.5	9.6	8.0
36	10.0	8.3	9.7	9.3
39	9.9	8.5	9.5	8.2
42	9.5	8.0	9.2	7.9
45	8.9	8.3	10.2	8.8
Average	9.1	8.3	9.4	8.5

The average total periodic changes in weight of floury corn (Lot No. 1) and horny corn (Lot No. 2) were 9.1 and 8.3%, respectively. If the average of horny corn (8.3%) is taken as a basis, the total periodic change for the 3-day periods was approximately 10% greater for the floury than for the horny corn. Similar results were obtained for lots Nos. 3 and 4.

Under usual conditions of storage of seed corn there is generally a slight fluctuation in relative humidity of the atmosphere. Change in relative humidity causes a change in moisture content of corn. Such change in moisture content is greater in amount and more rapid in starchy than in horny corn.

SUMMARY

1. Using the weight of corn at the beginning of the test as a basis, floury corn absorbed more water in humid air and lost more water in dry air than horny corn during each 3-day period for the first 12 days.

2. After the first 12 days, floury corn weighed approximately the same as horny corn at the end of 3-day periods in humid air, but floury corn weighed less than horny corn at the end of 3-day periods in dry air.

3. Using the average 3-day change in weight of horny corn as a basis, the change in weight of floury corn for a 3-day period was approximately 10% greater than that of horny corn.

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DEPOSITION AND UTILIZATION OF RESERVE FOODS IN ALFALFA PLANTS[1]

W. A. LEUKEL[2]

INTRODUCTION

That mineral nutrients and organic compounds accumulate in plants and are utilized for future growth has long been recognized, but a knowledge of how such storage and utilization are influenced by various agricultural practices and the relation of these to the problems of plant production is but now coming to be more fully appreciated.

Recent work on horticultural plants has demonstrated that their growth and fruit production are directly related to the kinds and quantities of organic foods manufactured by and stored within themselves. Many orchard practices are now based on plant compositions, as well as soil nutrient materials available, or made available, through cultural methods. That a similar relationship concerning storage and utilization of organic foods obtains in some herbaceous plants, especially perennials, is beyond doubt. Just what the relationships are for specific plants still remains to be determined, but progress in this study is being made.

Cutting trials on alfalfa over a period of years at the Kansas and Wisconsin Experiment Stations have shown that yields are progressively decreased, stands deteriorated, and root growth of the plants retarded with early and frequent cuttings. At the Wisconsin Experiment Station the physiological responses of the plants and the chemical composition of the roots have substantiated the hypothesis that new top growth, especially after the cutting of a crop, is initiated in a large measure at the expense of the previously deposited root reserves; and, unless such reserves could be partially or wholly replenished between periods of cutting the tops, it would follow that such reserves would become severely reduced, tending to diminish progressively the amount of new growth following each cutting to the point of extinction. A certain quantity and maturity of top growth was found necessary in order that, through photosynthetic activity, organic reserves in excess of the immediate growing needs of the plants could be formed so as to replenish the losses sustained by the roots through the production of new top growth.

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The purpose of the present work is to investigate further the effects of frequent cuttings of alfalfa on the reserves in the roots and the subsequent growth of the plants. The experiments have dealt with plants in successive stages of growth throughout the growing season from early spring until late fall and early winter when the plants become dormant.

HISTORY

Leclere du Sablon (1)[3] demonstrated the storage of hydrolyzable carbohydrates in the root and branches of pear and chestnut trees and the seasonal variations in the quantity of these materials. An increase was noted from May to September and a decrease from September to May. Comparable results were found in a similar study of the apple tree by Curtis (2).

Kraus and Kraybill (3) demonstrated that a change in the carbohydrate-nitrogen relation in plants accompanies a variation in their growth and fruitfulness, and that pruning the plant and proper nitrate and moisture supply in the soil are factors in controlling the variations in these reserves.

Hooker (4), in studying the seasonal changes in the chemical composition of apple spurs, found starch accumulation associated with low total nitrogen.

Harvey and Murneek (5) found that changes in the carbohydrate and nitrogen content of apple spurs resulted by defoliation of the spurs.

Leclere du Sablon (6) found the sucrose in the bulb of the onion high in autumn and winter and low in spring with the beginning of top growth. He found similar variations in the sugars and starches in the bulb of the meadow saffron.

That new top growth in herbaceous plants, especially after a cutting has been made, is initiated at the expense of previously deposited organic reserves was propounded by Waters (7) 20 years ago. He found that early cutting of timothy retarded the development of the bulbs of the plants and left them in a somewhat exhausted condition for the next season's growth.

The work of Waters on timothy was further substantiated by Trowbridge, Haigh, and Moulton (8). They found a steady increase in the dry matter of the bulb during the growing season which became constant before the ripening of the tops. The material stored was principally in the form of nitrogenous matter and nitrogen-free extract. The greatest increase in storage took place in the bulbs between the full bloom stage and the stage of seed formation.

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[3] Reference by number is to "Literature Cited," p. 623.

The work of Demmy (9) on the absorption of soil nutrients and the storage of structural and nutrient materials in the subterranean organs of meadow and pasture plants may be summarized as follows: Persistent clovers and grasses during their first development accumulate considerable nutrients in their rootstocks, about equal to the plant nutrients in an annual hay crop. A partial depletion of these nutrients takes place during the early growth of the aerial portion of the plant. Toward autumn with less vigorous vegetative growth, the replenishment of the rootstocks occurs annually, attaining its peak at the death of the tops. The principal nutrient materials determined were nitrogen, phosphorous, potash, and calcium. Fertilizers applied in the fall, early enough to be taken up by the plants, were found as effective as those applied at the proper time in the spring.

Wahlen (10), working on the wintering of perennial legumes, found that they did not appear to possess autonomic winter dormancy. A weak bud growth during the warmer winter days seemed to indicate that root growth also continued, but contraction of the tap root occurred. The reserve materials he found in the roots of the legumes included albumin and amids, nitrogen-free extract, principally in the form of starch, hemicellulose, and a small amount of fat. Hemicellulose was derived from starch during autumn and early winter. The specific weight of the root was found to be an index to the content of reserve material. New growth after cutting exhausted the reserves more han early spring growth. Cutting was found to affect the specific weight of the root, but it returned to normal if the final cutting was not made too near the beginning of winter. The specific weight of the root increased up to a certain degree, after which a decline followed. In these studies a maximum was attained in the first year in red clover, in the second to third year in meadow red clover, and in the third year in alfalfa.

Whiting and Richmond (11) determined the composition of biennial white sweet clover, tops and roots, at various periods in its life history. A decrease in the nitrogen, phosphorus, sulfur, and potassium content of the tops and an increase of these elements in the roots occurred in the later growth of the first year. There were some exceptions which may have been due to error in sampling. These changes in composition are interpreted as being due to the natural tendency of the plant to translocate the most important elements to its roots for winter storage.

The exhaustion of root reserves and its effect on future production and growth is reflected in the cutting trials on alfalfa at the Kansas Experiment Station (12). Alfalfa cut in the flower bud stages showed deterioration in yield and retarded growth at the end of the first season. Three years were required to bring about a similar result in plats cut in the tenth bloom stage, while those plats cut in the full bloom stage produced maximum yields for seven years before any deterioration in stand was noticeable. Plats cut in the seed pod stage of growth were vigorous after eight years of growth.

Cutting trials on alfalfa at the Wisconsin Experiment Station (13) indicate similar results. Decreased size and weight of the roots of the plants cut in the immature stages of growth were noticed, as compared to the roots of the plants cut in the more mature stages. A chemical analysis of the roots showed an increased percentage of reserves in the roots of the plants cut in the more mature stages of growth. These reserves consisted of sugars, dextrins, starches, hemicelluloses, and nitrogen.

MATERIALS AND METHODS

PREPARATION OF MATERIAL

The plants used in Experiments I and II were dug at approximately the same time of day for each series, namely, between 7:00 and 9:00 a. m. The top growth was separated from the roots and the green weight taken. The roots were washed in cold running water to remove adhering soil, cut to a uniform length of 8 inches, and then green weights taken. Both tops and roots were then cut into small pieces (one-fourth to one-eighth inch in length) and rapidly dried in a ventilated oven at 70°C (14). The dried material was then ground in a mill and pulverized in a Dreef mill (15) fine enough to pass through a 60-mesh sieve. It was preserved in dry, tightly stoppered bottles for chemical analysis in a dry room at ordinary room temperature.

The plants for Experiment III were prepared in a similar manner as described for Experiments I and II, but the green material was preserved in 95% ethyl alcohol for analysis. The roots and tops were cut into small pieces and 250 grams of each placed in wide-mouthed bottles. Enough boiling concentrated 95% alcohol was added to each to insure a concentration of 75%. The bottles were then stoppered with corks covered with tinfoil and placed in a dry room for analysis. Three 15-gram samples of each, green tops and roots, were placed in an electric oven at 103°C to determine the percentage of dry matter. All results are computed on a dry weight basis except percentage of dry matter.

METHODS OF ANALYSIS

EXPERIMENTS I AND II

Available carbohydrates.—In Experiments I and II, 3-gram samples were used for analysis and results computed on a dry weight basis. The reducing power of the various carbohydrate extractions was determined by the standard Shaeffer-Hartmann (16) volumetric method of sugar analysis after appropriate hydrolysis where necessary. Results for all carbohydrate compounds were computed on the basis of glucose. An ether extraction (alcohol-free, anhydrous ether) was made for 18 hours to remove chlorophyll, fats, waxes, resins, etc., before extracting any of the carbohydrates in order to facilitate complete carbohydrate extraction.

Sugars.—Sugars were extracted on a heated sand bath with 90% ethyl alcohol for one-half hour under a reflux condenser. The alcohol was kept just simmering during this process. After evaporating nearly all the alcohol at 50° to 60°C, the syrup was taken up with distilled water, clarified with neutral lead acetate, and filtered through dry folded filter paper. A sufficient quantity of nine parts of anhydrous Na_2SO_4 and one part Na_2CO_3 was added to the filtrate to remove any excess lead. After filtering the solution through double-folded dry filter paper, it was made up to 250 cc volume. Aliquots from the clear solution were used to determine reducing and total sugars. Fifty-cc aliquots without hydrolysis were used to determine reducing sugars. A 50-cc aliquot was diluted to 90 cc, 10 cc concentrated HCl (sp.gr. 1.12) added, and hydrolyzed for an hour. The reducing power was then determined for total sugars after neutralizing with 40% NaOH.

Soluble starches and dextrins.—After removing the sugars from the sample, 50 cc of water were added to the residue in a beaker, and a water extraction made at room temperature for one hour with frequent stirring to remove the dextrins and soluble starch. After filtering this mixture, the residue was washed until the filtrate reached a volume of 90 cc. Ten cc of concentrated HCl (sp.gr. 1.12) were added to the filtrate which was then hydrolyzed on a sand bath under a reflux condenser for two and one-half hours. The solution was then cooled, neutralized with 40% NaOH, and made up to 250 cc volume. Fifty-cc aliquots were taken to determine the reducing power.

Starch.—The residue, after extraction of dextrins and soluble starch, was washed into a beaker and the volume of the mixture made up to 50 cc. This mixture was heated to boiling to change the starch to a paste. The temperature was then lowered to 38°C, 10 cc of fresh saliva added, and digested at 38°C for one-half hour. At the end of the digestion period the mixture was brought to boiling, filtered, and the residue washed thoroughly, bringing the filtrate up to 90 cc volume. Ten cc of concentrated HCl (sp. gr. 1.12) were added to the filtrate which was then hydrolyzed on a heated sand bath under a reflux condenser for two and one-half hours. The solution was then cooled, neutralized with 40% NaOH, and made up to 250 cc volume. Fifty-cc and 25-cc aliquots were used to determine the reducing power.

Hemicelluloses.—To remove hemicelluloses, the final residue (after removal of starches) was washed into an Erlenmeyer flask, made up to 90-cc volume, 10 cc concentrated HCl (sp. gr. 1.12) added, and hydrolyzed for two and one-half hours. The solution was then cooled, neutralized, clarified, and made up to 250 cc volume, from which 25-cc aliquots were taken to determine reducing power.

Total nitrogen.—A 3-gram dry sample was used to determine total nitrogen by the Kjeldahl method.

EXPERIMENT III

Available carbohydrates, sugar.—The alcohol extract from the preserved material for Experiment III, after standing for several weeks, was filtered into a beaker. The preserved material was placed upon the filter paper and washed with a volume of warm 95% alcohol equal to the volume of the extract. The filtrate was evaporated slowly at a boiling temperature to a 200 cc volume on a sand bath. The evaporation was then completed on a water bath at 50°C under reduced pressure. The residue was taken up with distilled water, clarified, deleaded, and made up to a 500 cc volume. Twenty-five-cc aliquots were used to determine reducing sugars. A similar aliquot diluted to 90 cc volume, plus 10 cc concentrated HCl (sp. gr. 1.12), was hydrolyzed, cooled, neutralized, and reducing power determined for total sugars in like manner. The residue on the filter paper was dried in a ventilated oven at 70°C. This dried material was ground in a mill and then pulverized in a Dreef mill fine enough to pass through a 60-mesh sieve. It was then preserved in dry, tightly corked bottles for analysis. Four-gram samples were used for carbohydrate analysis. The reducing and total sugars were computed on the entire sample and added to the respective weights of similar sugars found in the alcohol extract. The percentage of each sugar was then computed on the total dry material in the preserved sample.

Polysacherids.—Other carbohydrate compounds were run on the residue as previously described for Experiments I and II.

Soluble forms of nitrogen.—The various forms of soluble nitrogen (17) in the roots and tops of the plants in Experiment III were determined on the green material and the percentage of each computed on dry weight basis.[4] One hundred grams of the green material were triturated in a mortar with quartz sand which had been previously washed free from foreign material. About 5 cc of ether were added to promote plasmolysis and water was added as required to give proper consistency for trituration. It was then extracted with distilled water through four thicknesses of cheesecloth and the extract filtered through moist paper pulp with suction to a volume of 1,900 cc. It was then made up to 2,000 cc volume with distilled water drawn through the paper pulp.

One hundred-cc aliquots of this extract were used to determine total water soluble nitrogen by the Kjeldahl method. Two hundred and fifty-cc aliquots were brought to boiling and then the soluble proteins precipitated with 10% acetic acid. After filtering, the precipitate was washed with hot water, and then transferred to a Kjeldahl flask and total nitrogen therein determined by the Kjeldahl method. The total nitrogen in the filtrate was determined by the same method.

Insoluble nitrogen.—Insoluble nitrogen was determined by subtracting the total water soluble nitrogen from the total nitrogen.

Total nitrogen.—Total nitrogen was determined on 3-gram samples of the originally dried material.

EXPERIMENTAL DATA

EXPERIMENT I

Experiment I was conducted to determine the effect of early and frequent cuttings on the top and root growth of transplanted alfalfa plants in comparison with less frequent cuttings made in more mature stages of growth. Common and Grimm varieties that had been seeded during the summer of 1920 and cut three times in the full-bloom stage of growth during the season of 1921 were dug in 1922 and transplanted in rows. The mature top growth was cut back at the time of transplanting and the roots were cut to a uniform length of 8 inches. The adhering soil was removed from the roots and their green weights recorded. Three such transplanted plats were established, one of common alfalfa, C^2, and one, of the Grimm variety, G^2, on July 8, 1922, and another of Grimm, G^1, on May 13, 1922. No cutting was made on these plants during the summer of 1922, except for the removal of top growth at transplanting. They passed through the winter of 1922–23 in good condition.

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[4] The total nitrogen in the water extract is designated in this work as total water soluble nitrogen, that in the precipitate as soluble protein nitrogen, and that in the filtrate as soluble protein-free nitrogen.

In 1923, the top growth of part of the plants of the common variety in plat C^2 and of the Grimm variety in plats G^2 and G^1 was cut three times when in a succulent stage of growth on May 21, June 28, and July 14, respectively, and yields for each calculated on the basis of 100 plants as recorded in Table 1. The remaining plants in these plats were allowed to mature until seed pods had begun to form before the first cutting was made on June 28, 1923, and another cutting in a semi-mature condition was taken on July 14, 1923. The first cutting of this series was made on the same day, June 28, as the second cutting of the succulent series and the last cutting of both series was made on July 14. The average amount of dry top growth for plants cut in the mature and succulent stages of growth is, therefore, the amount produced over the same period of time, the only difference in treatment being the frequency and time of cutting. The total yield of dry top growth on the basis of 100 plants receiving the three cuttings in the succulent stages was (Table 1) 1,652.8 grams for the common alfalfa of plat C^2, 3,230 grams for the Grimm of plat G^2, and 2,660.3 grams for the Grimm of plat G^1, or an average of 2,422 grams. With the two cuttings in the more mature stages the total yield of dry top growth during the same period of time was 5,483.5 grams for the common in plat C^2, 4,915.2 grams for the Grimm in plat G^2, and 7,648.3 grams for the Grimm in plat G^1, or an average of 5,748 grams, which is nearly 2.4 times that secured with three cuttings in the succulent stages.

The effect of these cutting treatments on root growth, including crowns, was also measured. Green weights of the roots were taken when they were transplanted on July 8 and May 13, 1922, and again when dug on July 14, 1923, as shown in Table 2. With the three cuttings in the succulent stages the average percentage of increase in root growth as determined by green weights on date of transplanting and again when dug was 232.4, 311.3, and 391.8, respectively, for the plants in plats C^2, G^2, and G^1, while for the roots of plants receiving cuttings in the more mature stages, the percentage of increase was 469.1, 668.1, and 1,159.5, respectively. On a dry basis the roots (with crowns) of plants cut in the succulent stages averaged

TABLE 1.—*Effect of cuttings of the top growth of alfalfa plants in the succulent and mature stages of growth on yields and root growth, all cuttings made in 1923.*

Variety	Plat No.	When transplanted, 1922	When dug and date of last cutting, 1923	Number of roots on which weighings were made		Number of plants on which cuttings were made		Number of cuttings in 1923		Yield of dry top growth in grams per 100 plants		Dry weight per 100 roots (without crowns) in grams		Percentage dry matter in roots (without crowns) when dug	
				Succulent	Mature	Succulent	Mature	Succulent	Mature	Succulent	Mature	Succulent	Mature	Succulent	Mature
Experiment I, Alfalfa Seeded in 1920															
Common	C^2	July 8	July 14	10	20	17	20	3	2^a	1,652.8	5,483.5	320.0	647.5	25.4	32.5
Grimm	G^3	July 8	July 14	10	21	10	21	3	2^a	3,230.0	4,915.2	465.0	630.9	25.9	28.7
Grimm	G^1	May 13	July 14	19	12	21	12	3	2^a	2,660.3	7,648.3	297.9	745.8	22.5	28.7
Experiment II, Alfalfa Seeded in 1922															
Common and . Grimm	A^1	July 15	Nov. 5	43	59	64	61	6	3^b	2,553.4	5,396.5	379.3	1,147.9	30.1	38.5
Four rows common	B^2	Not transplanted, but seeded July 15	Nov. 6	300	548	Four rows	Four rows	5	3^b	1.266.9[c]	1,620.5[c]	24.7	74.01	24.4	33.1
Four rows Grimm	B^3		Nov. 6	111	288	Four rows	Four rows	5	3^b	951.0[c]	1,587.5[c]	30.1	80.8	28.2	33.04

[a] One cutting when in early seed-pod formation and one cutting when in semi-mature stage on July 14, 1923.

[b] Same as above, except one additional cutting taken in November, 1923, when in fall dormancy.

[c] These are yields from four rows of plants and not 100 plants.

TABLE 2.—*Effect of cuttings in succulent stages in comparison with cuttings in the more mature stages of top growth on root growth, including crowns, of transplanted common and Grimm alfalfa plants three years old.*

Variety	Plat No.	Number of plants	When trans-planted, 1922	When dug, 1923	Average green weight in grams of each root when transplanted	Average green weight in grams of each root when dug	Percentage increase in green weight	Average dry weight in grams of roots when dug (with crowns)	Percentage dry matter in roots (including crowns) when dug
Common[a]	C^2	10	July 8	July 14	5.70	18.95	232.4	6.25	32.9
Grimm[a]	G^2	10	July 8	July 14	8.18	33.65	311.3	9.15	27.2
Grimm[a]	G^1	19	May 13	July 14	4.76	23.41	391.8	6.98	29.8
Common[b]	C^2	20	July 8	July 14	6.80	38.7	469.1	11.60	30.3
Grimm[b]	G^2	21	July 8	July 14	5.28	40.59	668.1	12.40	30.6
Grimm[b]	G^1	12	May 13	July 14	3.71	46.79	1,159.5	14.82	31.7

[a] Cut three times in succulent stages of growth.

[b] Cut once in early seed pod stage and later in semi-mature stage, July 14, 1923.

TABLE 3.—*Comparison of the percentage and amount of available carbohydrates and total nitrogen in the roots (without crowns) of plants in Experiments I and II cut in succulent and mature stages of top growth.*

Variety	Plat No.	When seeded	When transplanted	When dug and date of last cutting, 1923	Number of roots		Number of cuttings of top growth		Total sugars		Soluble starches and dextrins		True starch		Hemicelluloses		Total available carbohydrates		Total nitrogen	
					Succulent	Mature	Succulent	Mature	Succulent	Mature	Succulent	Mature	Succulent	Mature	Succulent	Mature	Succulent	Mature	Succulent	Mature
Experiment I, Percentage of Carbohydrate Compounds, Total Carbohydrates, and Total Nitrogen																				
Common	C^2	1920	July 8	July 14	10	20	3	2^a	4 56	4.972	1.45	2 662	2.36	2 812	12.72	13.5	21.09	23.946	1.53	2.22
Grimm	G^2	1920	July 8	July 14	10	21	3	2^a	4 185	3.925	1 625	1.825	1 387	3.525	12.425	12.425	19 622	21.737	1.25	2.02
Grimm	G^1	1920	May 13	July 14	19	12	3	2^a	3 59	3.55	1 68	1.93	1.29	2.68	12.1	12.5	18 66	20.66	1.58	1.83
Experiment II, Percentage of Carbohydrate Compounds, Total Carbohydrates and Total Nitrogen																				
Grimm and Common	A^1	May 15, 1922	July 15	Nov. 5	43	59	6	3^b	10.58	8.20	3.134	3.283	5.96	19.08	9 58	11.855	29.254	42.41	1.56	2.13
Common	B^2	July 15, 1923	Not	Nov. 6	300	548	5	3^b	12.08	8.99	3 489	2.91	8 98	17.26	8.465	11.09	33.014	40.25	1.525	2.222
Grimm	B^3	July 15, 1922	transplanted	Nov. 6	111	288	5	3^b	8.375	12.5	3.625	4.55	5.625	14.03	10.2	10.3	27.825	41.65	1.46	2.192
Experiment I, Amount in Grams of Carbohydrate Compounds, Total Carbohydrates, and Total Nitrogen in 100 Roots																				
Common	C^2	1920	July 8	July 14	10	20	3	2^a	14.592	32.243	4.64	17.236	7.552	18.207	40.704	87.4125	67.488	155.25	4.896	14.3745
Grimm	G^2	1920	July 8	July 14	10	21	3	2^a	19 470	24.996	7.556	11 515	6.449	22.239	57.776	78.389	91.242	137.476	5.812	12.744
Grimm	G^1	1920	May 13	July 14	19	12	3	2^a	10.604	26.476	5.005	14.394	3 843	19.987	36.046	93.225	55.588	154.082	4.707	13.648
Experiment II, Amount in Grams of Carbohydrate Compounds, Total Carbohydrates, and Total Nitrogen in 100 Roots																				
Grimm and Common	A^1	May 15, 1922	July 15	Nov. 5	43	59		3^b	40.13	94.13	11.90	43.88	22.61	219.02	36.34	136.08	110.80	486.92	5.92	24.45
Common	B^2	July 15, 1922	Not	Nov. 6	300	548	56	3^b	2 98	5.65	0.86	2.15	2.18	12.77	2.09	8.21	8.15	29.79	0.37	1.64
Grimm	B^3	July 15, 1922	transplanted	Nov. 6	111	288	5	3^b	2.52	10.11	1.09	3.69	1.69	11.57	3.07	8.33	8.37	33.69	0.44	1.77

[a] One cutting when in early seed-pod formation and one cutting when in semi-mature stage on July 14, 1923.

[b] Same as above, except one additional cutting taken in November, 1923, when in fall aordmncy.

7.35 grams, while with those cut in the more mature stages the roots averaged 12.64 grams, or nearly twice as much. There was only a small difference in the average percentage of dry matter in the roots (with crowns) of the two cutting series, but when the crowns were removed the percentage of dry matter in the remainder of the root was very much higher for the plants cut in the more mature stages, as shown in Table 1.

Chemical analyses of the roots (without crowns) of the plants cut in succulent and mature stages do not reveal (Table 3) wide general differences in the percentages of sugars, soluble starches and dextrins, true starch, and hemicelluloses, but the quantity of these carbohydrates and the percentage and amount of total nitrogen are significantly higher for the roots of the plants cut in the mature stages. Applying the percentages to the average weight of the roots brings about very striking and consistent quantitative differences in each of the carbohydrate compounds and in the total carbohydrate and nitrogen compounds (Table 3). The roots of the plants in the three plats (C^2, G^2, and G^1) receiving the cuttings in the more mature stages contained, on the average, more than twice the amount of total available carbohydrates and of total nitrogen, approximately twice the amount of sugars and hemicelluloses, nearly four times the amount of true starch, and nearly three times the amount of soluble starches and dextrins as were found in the roots of the plants with tops cut in the succulent stages of growth.

EXPERIMENT II

Experiment II was conducted to determine the effect of more frequent cuttings on younger alfalfa plants than those used in Experiment I. Plat A^1 consisted of seedling Grimm and common alfalfa plants sown in rows May 15, 1922, and transplanted in rows July 15, 1922. These plants grew during the summer of 1922 and received no cutting treatments. In the spring of 1923, the plants were divided into two sections, one being cut six times in the succulent stages of growth and the other three times in more mature stages. In each section on the day of the last cutting, November 5, 1923, when the plants were in a stage of fall dormancy, the roots were dug and cut to a uniform length of 8 inches. The green and dry weights of the roots (without crowns) were taken, percentage of dry matter calculated, and chemical analyses were made.

Plat B^2 consisted of four rows of common alfalfa plants and plat B^3 consisted of four rows of the Grimm variety, all seeded on July 15, 1922. These were not transplanted and no cuttings were made during the summer of 1922. In the spring of 1923, they were divided

TABLE 4.—*Yields of dry top growth of alfalfa plants cut early and frequently in comparison with less frequent and more mature cuttings, Experiment II.*

Variety and number of plants or rows	Plat No.	When seeded, 1922	When transplanted, 1922	Average yields in grams of dry top growth for 1923 cuttings May 21	June 28	July 15	Aug. 11	Sept. 4	Nov. 6	Total
Tops Cut Five and Six Times in Succulent Stages. Plants Dug Nov. 6.										
Grimm and common, 64 plants	A^1	May 15	July 15	1,043.7^a	692.1^a	437.5^a	136.7^a	157.0^a	86.2^a	2,553.4^a
Four rows common	B^2	July 15	Not	644.0^b	346.5^b	182.5^b	65.0^b	Not cut	28.9^b	1,266.9^b
Four rows Grimm	B^3	July 15	transplanted	509.0^b	275.5^b	130.0^b	25.0^b	Not cut	11.5^b	951.0^b
Tops Cut in Early Seed-pod Stage, Semi-mature Stage, and in Fall Dormancy. Plants Dug Nov. 6.										
Grimm and comomn, 61 plants	A^1	May 15	July 15	Not cut	3,632.1^a	Not cut	950.8^a	Not cut	977.3^a	5,396.5^a
Four rows common	B^2	July 15	Not	Not cut	1,015.2^b	Not cut	387.5^b	Not cut	217.8^b	1,620.5^b
Four rows Grimm	B^3	July 15	transplanted	Not cut	1,102.0^b	Not cut	395.0^b	Not cut	90.5^b	1,587.5^b

[a] On basis of 100 plants.
[b] Per four rows of plants.

into two sections. The plants in one section were cut five times in succulent stages of growth and in the other section three times in more mature stages. On the date of the last cutting which was on November 6, 1923, in each section the plants were treated in a similar manner as those in plat A^1.

Eleven plants, or 18.7% of all the plants in plat A^1, given the six cuttings in the succulent stages died, while those cut in the more mature stages suffered a loss of only 3.27% during the growing season of 1923. The yield in dry weight of top growth of 64 plants (Table 4) shows a gradual decrease with each, except one, of the six successive cuttings in the succulent stages from 1,043.7 grams of dry top growth calculated on the basis of 100 plants for the first cutting to 86 grams for the last cutting. This decrease is much less marked with the cuttings of 61 plants in the more mature stages of growth (Table 4) where the first cutting yielded 3,632.1 grams, the second 950.8 grams, and the last 977.3 grams of dry top growth calculated on the basis of 100 plants. In total yields, the three cuttings in the more mature stages produced dry top growth at the rate of 5,396.5 grams per 100 plants in contrast to less than half or 2,553.4 grams for six cuttings in the succulent growth stages.

The roots (without crowns) of the plants (A^1) receiving the six cuttings in the succulent stages of growth contained 30.1% (Table 1) dry matter and had a dry weight of 379.3 grams calculated on a basis of 100 plants, while in those cut three times in the more mature stages the percentage of dry matter was 38.5 and the dry weight, calculated on the basis of 100 roots, was 1,147.9 grams, or three times that of those cut in the immature growth stages.

Chemical analyses of the roots (without crowns) for the above cutting treatments in plat A^1 revealed significant differences in percentages and striking differences in quantities of carbohydrate compounds and total nitrogen (Table 3). The percentage of total carbohydrates in the roots (not including crowns) was 42.41 for the plants cut in the more mature stages and 29.25 for those cut in the succulent stages, while on a quantitative basis 100 roots of plants in the former series contained 486.92 grams of total carbohydrates in contrast to less than one-fourth this amount, or 110.80 grams, for the roots of those in the latter series. The percentage of true starch was more than three times and the amount nearly ten times as abundant in the roots of the plants cut in the more mature stages of growth. On a percentage basis all carbohydrate compounds and also total nitrogen were higher in the roots of the plants cut in the mature growth stages, except in case of sugars. Quantitatively, all compounds showed consistent and remarkable differences—the roots of plants cut in more mature stages having 2 times the amount of sugars, almost 4 times the amount of soluble starches and dextrins, approximately 10 times the amount of true starch, 3.7 times the amount of hemicelluloses, 4 times the amount of total carbohydrates, and 4 times the amount of total nitrogen as did the roots of the plants cut in the succulent stages of growth.

Alfalfa in plats B^2 and B^3 was not transplanted but was seeded in rows on the same day, July 15, 1923, that the seedling plants of plat A^1 were transplanted. The chief differences between plats A^1, B^2, and B^3 are first, in the matter of variety; second, in that five cuttings in the succulent stages were applied to plats B^2 and B^3, while six such cuttings were given to plat A^1; and third (and most important), that the transplanted plants of plat A^1 had far less competition with each other, or in other words, had a much greater opportunity to expand their root growth and top growth than did the crowded plants in the rows of plats B^2 and B^3. The yields of dry top growth in plats B^2 and B^3 are not on the basis of 100 plants, but are the yields secured from rows of plants of equal length. On this basis, five cuttings in the succulent stages yielded (Table 1) 1,266.9 grams of dry top growth for the common alfalfa in plat B^2 and 951.0 grams for the Grimm in plat B^3, while the three cuttings in the more mature stages of the common alfalfa in plat B^2 yielded 1,620.5 grams and of the Grimm in plat B^3 1,587.5 grams, making a 28 % increase for the cutting of the common and a 67% increase for the cutting of the Grimm in the mature growth stages.

On account of the crowded condition of the plants in plats B^2 and B^3 in contrast to the transplanted plat A^1, the root growth of the former plats was only about one-tenth the weight of the roots from plat A^1. However, the comparative effects of the cuttings on the plants in the mature and succulent stages of growth on root growth in plats B^2 and B^3 were about the same in the dry weight of roots and in percentage of dry matter (Table 1). The roots of both Grimm and common alfalfa (without crowns) produced about three times the dry weight of roots when cut in the more mature stages of growth. The roots of the common alfalfa had 24.4% dry matter when cut in succulent stages, while the Grimm cut at the same periods had 28.2%. When cut in the more mature stages, the percentage of dry matter in both Grimm and common was about the same, or 33.04 and 33.1, respectively.

Chemical analysis of the roots in plats B^2 and B^3 shows practically the same comparative differences for the plants cut in the succulent and mature growth stages as were found in plat A[1] (Table 3), the most important exception being in the percentage and quantity of sugars in the roots of the Grimm plants in plat B[3]. Here the roots of the plants cut in the succulent stages contained 8.37% sugars, which is significantly less than the roots of those cut in the mature growth stages with a sugar content of 12.5%. With the common alfalfa in plat B[2] the reverse of this was found and likwise in plat A[1]. Consequently, with cuttings of the plants in the mature stages the Grimm in plat B[3] had four times the amount of sugars, while the common in plat B[2] and the plants of plat A[1] had only about twice the quantity of sugars in the roots cut in the mature stages as was present in the roots of those cut in the succulent stages. The soluble starches and dextrins showed higher percentages, with the cutting of Grimm in the mature stages in plat B[3] than with those cut in the succulent stages. The reverse, however, was true in the common alfalfa of plat B[2] where these carbohydrates were lower for the plants cut in the mature stages, as compared to those cut in the immature stages of growth.

The chemical data in Table 3 indicate a few significant comparisons between the results obtained in Experiments I and II as a result of the different cutting treatments. Plants in Experiment I were in their fourth season's growth and part cut three times in the succulent stages and two times in the more mature stages of growth and dug July 14, 1923. In Experiment II the alfalfa plants were in their second season's growth and part cut five to six times in the succulent stages and the remainder three times in the more mature stages. On November 5 and 6, 1923, these plants were dormant and the roots were dug. In all alfalfa plants of Experiments I and II the total yield of top growth was greater for plants cut in the more mature stages than with those cut in the immature growth stages. Likewise, the roots of the plants cut in the more mature stages were much heavier and higher in percentage of dry matter. Percentages of sugars, soluble starches and dextrins, true starch, and total available carbohydrates are higher in the roots of the younger plants of Experiment II than with the older plants of Experiment I. This statement holds true for plants cut in both the mature and immature stages of growth. Little difference is shown in the percentages of total nitrogen in the roots of the plants with tops cut in the succulent stages in Experiments I and II, and a like similarity exists in the percentages of total nitrogen in the roots of plants cut in the more mature growth stages in both experiments. Very slight variation is noted in the quantity of total nitrogen in the roots of the transplanted alfalfa plants cut in the succulent stages of growth, but in quantity of total available carbohydrates those of Experiment II are considerably higher. The roots of the transplanted plants cut in the more mature stages of growth in Experiment II contain approximately twice the quanity of total nitrogen and three times the quantity of total carbohydrates when compared with an equal number of plants in Experiment I cut in the more mature growth stages. The roots of the plants in plats B^2 and B^3 of Experiment II were grown under more crowded conditions and, therefore, cannot be compared with those of plat A^1 or with the plants of Experiment I on a quantitative basis.

EXPERIMENT III

The striking quantitative difference in the reserves of roots of alfalfa cut in the succulent stages of growth and those cut in the more mature stages in Experiments I and II indicates variations in the distribution of foods between the tops and roots at different periods of growth. An effort was made to measure these variations and 14 rows of Grimm alfalfa were seeded for this purpose on July 14, 1923. The plants from this seeding showed a uniform healthy stand the following spring. At the first sign of top growth, April 13, 1924, 100 plants, selected from various parts of the plat, were dug. A similar group of plants was dug in the same way when in a succulent stage of growth on May 26, 1924, when flower buds had formed on June 21, when in full bloom on July 10, and when seed pods had matured on August 7. At this time the tops of all the remaining plants were cut. New growth was slow to start on account of drought and other factors. On September 13, 1924, another group of 100 plants was dug when the alfalfa was still in a succulent state of growth and again on October 22, when in a semi-dormant state. The last group of plants was dug December 6, 1924, when in a stage of winter dormancy. After each group was dug, the tops were separated from the roots. The crowns of the plants were included with the roots. All the roots were cut to a uniform length of 8 inches. The green and dry weights of the tops and roots were taken and recorded. Separate samples of the tops and roots from each group of plants were prepared for chemical analysis. The top growth produced after the plants were cut in the seed-pod stage remained in a vegetative growth condition. No flower buds or blossoms were noted on the plants.

The plants dug early in the spring (April 13, 1924) had very little top growth when compared with later diggings (Tables 5 and 6). The roots show a high percentage of reserve foods. They are high in moisture, total sugars, hemicelluloses, total nitrogen, and the water soluble forms of nitrogen. Soluble starches and dextrins, true starch, dry matter, and insoluble nitrogen are apparently low when compared with these compounds in the plants in some of the successive stages of growth. The small quantity of top growth of these plants does not show such large variations in organic constituents as are found in the roots, but the tops are also relatively high in total sugars, hemicelluloses, total nitrogen, and the water soluble forms of nitrogen, and they are high in moisture.

Compared with the previous stage of growth, the roots in the group of the succulent plants (dug May 26, 1924) show approximately a 50% decrease in the percentage of total sugars, true starch, and hemicelluloses. The percentage of soluble starch and dextrin increased slightly. Almost a uniform decrease is shown in all forms of nitrogen. Little difference is noted in the percentage of moisture and dry matter. The tops show a slight increase in percentage of soluble starches and dextrins, starches, total carbohydrates, and insoluble nitrogen, and a decrease in total sugars, total nitrogen, and the water soluble forms of nitrogen (Tables 5 and 6).

A marked increase is found in the percentage of most of the carbohydrate and nitrogen compounds in the roots of plants dug in the flower-bud stage, June 21, 1924. A slight increase is found in the soluble starches and dextrins. The hemicelluloses and total carbohydrates show over a 100% increase, while the true starch is four times as high in percentage. All forms of nitrogen show an increase in percentage, except the insoluble nitrogen which is slightly lower. A slight increase is noted in the percentage of dry matter.

Compared with the succulent stage of growth, the tops show a higher percentage of total carbohydrates, hemicelluloses, and soluble protein-free nitrogen. A decrease in the percentage of total sugars, soluble starches and dextrins, true starch, water soluble nitrogen, soluble protein nitrogen, insoluble nitrogen, and total nitrogen is shown.

The roots of plants dug in full bloom (July 10, 1921) show a marked increase in the percentage of soluble starches and dextrins, total carbohydrates, and dry matter, with a slight increase in the hemicelluloses. The percentages of total nitrogen and insoluble nitrogen show a decided decrease, while all the soluble forms of nitrogen are higher than in the flower-bud stage of growth. Compared with the previous stage, the tops are higher in total sugars, soluble starches and dextrins, hemicelluloses, total carbohydrates, dry matter, and all forms of water soluble nitrogen. They are lower in total nitrogen, insoluble nitrogen, and moisture.

TABLE 5.—*Percentage and weight in grams of dry matter and different forms of carbohydrates in roots and tops of 100 alfalfa plants dug at different stages of growth during growing season of 1924.*

Stage of growth, 1924		Dry weight		Carbohydrate compounds Total sugars		Soluble starches and dextrins		True starch		Hemicellulose		Total carbohydrates	
		Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops
Early Spg.,	Percentage	26.80	20.50	11.187	6.1257	2.787	1.921	6.018	1.963	11.287	10.913	31.279	21.922
April 13	Wt. in gms.	47.88	67.00	5.3565	4.1037	1.3346	1.2870	2.8815	1.3152	5.4044	7.3117	14.9770	14.0177
Succulent,	Percentage	25.70	20.50	5.006	4.931	3.713	3.493	3.735	3.887	6.805	10.695	19.259	22.006
May 26	Wt. in gms.	63.22	259.23	3.1647	12.7826	2.3475	6.4626	2.3612	10.0762	4.3021	17.7246	12.1755	57.0461
Flower-bud,	Percentage	28.02	20.10	5.278	3.971	5.5075	1.45	17.842	2.0937	12.127	12.037	40.7515	19.551
June 21	Wt. in gms.	136.10	539.68	7.1792	21.4306	5.7111	7.8253	24.2829	11.2982	16.5048	64.961	55.4627	105.5166
Full-bloom,	Percentage	36.96	24.60	5.145	3.091	14.387	2.187	17.639	1.923	12.5	14.5	49.352	21.701
July 10	Wt. in gms.	221.76	658.35	11.4064	20.3495	31.8959	14.3981	39.1056	12.5440	27.7125	95.4607	110.1206	142.8685
Seed-pod,	Percentage	56.01	43.00	4.993	1.558	6.662	1.35	20.03	2.0187	9.562	12.65	41.21	17.5767
Aug. 7	Wt. in gms.	823.84	1887.70	41.1093	29.4103	54.8509	25.483	64.915	38.1069	78.727	236.794	339.575	331.7953
Succulent,	Percentage	30.25	21.48	5.321	4.043	3.968	1.662	6.057	2.675	6.737	13.395	22.063	21.775
Sept. 13, after cutting August 9	Wt. in gms.	220.97	378.79	11.7578	15.3144	8.768	6.2954	13.3708	10.1326	14.8867	50.7389	48.7835	82.4815
Semi-dorm.,	Percentage	44.84	26.80	4.647	6.139	4.657	1.58	24.9	3.087	8.162	11.92	42.366	22.726
Oct. 22	Wt. in gms.	365.04	488.43	16.9634	29.9847	17.9999	7.717	90.8949	15.0780	29.7945	58.2208	155.5433	111.0002
Dormant,	Percentage	35.75	38.40	13.103	2.482	2.975	2.785	13.685	1.643	9.55	6.775	40.298	13.685
Dec. 6	Wt. in gms.	368.76	364.83	48.3186	9.0550	10.9706	10.1605	54.0970	5.9941	35.2165	24.7162	148.6029	49.9269

TABLE 6.—*Percentage and weight in grams of dry matter and different forms of nitrogen in roots and tops of 100 alfalfa plants dug at different stages of growth during the growing season of 1924, Experiment III.*

Stage of growth, 1924		Dry weight		Total water soluble nitrogen		Soluble protein nitrogen		Soluble protein-free nitrogen (by analysis)		Insoluble nitrogen (by subtraction)		Total nitrogen	
		Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots	Tops
Early spring, April 13	Percentage	26.8	20.50	2.5	2.53	0.638	1.21	1.86	1.305	1.1	1.31	3.6	3.82
	Wt. in gms.	47.88	67.00	1.1970	1.6951	0.30548	0.8107	0.8906	0.8744	0.5267	0.8643	1.7237	2.5594
Succulent, May 26	Percentage	25.7	20.5	1.145	2.00	0.4145	0.605	0.725	0.8125	0.9525	1.4345	2.0975	3.4345
	Wt. in gms.	63.22	259.23	0.72135	5.1846	0.2620	1.5593	0.4583	2.1062	0.6021	3.7186	1.3260	8.9032
Flower-bud, June 21	Percentage	28.02	20.10	1.641	1.34	0.585	0.676	1.074	0.666	0.662	1.12	2.31	2.46
	Wt. in gms.	136.1	539.68	2.233	7.2317	0.7961	3.6482	1.4617	3.5942	0.9009	6.044	3.1439	13.2761
Full-bloom, July 10	Percentage	36.96	24.60	1.68	1.66	0.6595	0.752	0.940	0.990	0.5074	0.493	2.1874	2.153
	Wt. in gms.	221.76	658.35	3.694	10.9286	1.4621	5.0507	2.0839	6.4976	1.1249	3.2456	4.8494	14.1742
Seed-pod, Aug. 7	Percentage	56.01	43.00	1.379	1.055	0.4927	0.4855	0.8477	0.613	1.306	1.63	2.685	2.65
	Wt. in gms.	823.84	1887.70	11.3838	19.9152	4.0565	9.1644	6.9760	11.5715	10.7528	30.1086	22.1066	50.0240
Succulent, Sept. 13, after cutting August 9	Percentage	30.25	21.48	1.407	2.145	0.553	1.390	0.83	0.742	0.808	1.905	2.215	3.295
	Wt. in gms.	220.97	378.79	3.1090	8.1250	1.2219	5.2651	3.0550	2.8106	1.7854	4.3561	4.8944	12.4811
Semi-dorm., Oct. 22	Percentage	44.84	26.80	1.859	2.229	0.8626	0.9232	0.7314	0.9054	0.6405	0.649	2.4995	2.878
	Wt. in gms.	365.04	488.43	6.7860	10.8871	3.1488	4.5091	2.669	4.2224	2.3381	3.1699	9.1241	14.057
Dormant, Dec. 6	Percentage	35.75	38.40	1.983	1.671	0.3550	0.6155	1.096	1.0184	0.843	0.996	2.826	2.667
	Wt. in gms.	368.76	364.83	7.3125	6.0963	2.7841	2.2455	4.0416	3.7154	3.1086	3.6337	10.4211	9.7300

The roots of the plants dug in the seed-pod stage (August 7, 1924) show a marked decrease in the percentage of soluble starches and dextrins, hemicelluloses, total carbohydrates, moisture, and the water soluble forms of nitrogen, and an increase in dry matter, starches, insoluble nitrogen, and total nitrogen. Compared with the previous stage of growth, the tops are higher in percentage of dry matter, starch, total nitrogen, and insoluble nitrogen, and lower in total sugars, soluble starches and dextrins, hemicelluloses, total carbohydrates, and all forms of water soluble nitrogen.

The second succulent stage of the plants occurred after the tops were cut in the seed-pod stage on August 9, 1924. The plants were dug on September 9, 1924. Analyses of the roots show a decrease in the percentage of all the carbohydrate and nitrogen compounds, except the soluble protein nitrogen and total sugars which show a slight increase in percentage. The greatest decrease in percentage is found in the total carbohydrates, true starch, and hemicellulose. A marked increase in the percentage of moisture occurred. The tops show an increase in the percentage of all the carbohydrate compounds over the seed-pod stage of growth. A corresponding increase occurs in the nitrogen compounds with the exception of soluble protein-free nitrogen which is somewhat lower. The tops are high in moisture and low in dry matter when compared with the tops of the plants in the seed-pod stage of growth.

A considerable increase in the percentage of all the carbohydrate compounds is noted in the roots dug in a semi-dormant stage on October 22, 1924, over that found in the roots of the plants in the previous stage of growth. Little variation is found in the percentage of total sugars and soluble starches and dextrins. A higher percentage of total nitrogen and water soluble nitrogen prevails over that of the roots of the plants in the second succulent stage of growth, but the other forms of nitrogen are lower. The roots of these plants are higher in dry matter and lower in moisture. The tops, when compared with the previous growth stage, are higher in percentage of total sugars, true starch, total carbohydrates, total water soluble nitrogen, soluble protein-free nitrogen, and dry matter, and lower in percentage of hemicelluloses, soluble protein nitrogen, insoluble nitrogen, total nitrogen, and moisture.

The roots of the dormant plants dug December 6, 1924, after the ground was frozen, showed a slight decrease in the percentage of total carbohydrates. The true starch shows a marked decrease in percentage, while a corresponding increase in the percentage of total sugars is shown. Hemicelluloses and moisture are somewhat higher and soluble starches and dextrins lower in percentage. All the forms of nitrogen show an increase in percentage, except the soluble protein nitrogen which is lower. The tops of the plants in this group were dry and mostly defoliated and all carbohydrate compounds were lower in percentage, except the soluble starches and dextrins. The insoluble nitrogen and the soluble protein-free nitrogen were higher in percentage than in the tops of the plants in the semi-dormant stage of growth. The other forms of nitrogen were lower in percentage. These tops were high in dry matter and low in moisture.

The quantity of carbohydrate and nitrogenous reserves in the plants do not follow the same trend as they do on a percentage basis through the consecutive stages of growth. The greatest quantity of these reserves is found in the seed-pod and in the semi-dormant stages of growth, although the highest percentage is found in the full-bloom stage. One also observes from data in Tables 5 and 6, that the increase and decrease in the percentage and quantity of dry matter through the consecutive growth stages is very similar in the roots and tops. In the early stages of growth both are low in percentage of dry matter and high in moisture. As they approach the seed-pod stage, both roots and tops increase in percentage of dry matter and decrease in water content. On September 13, 1924, when tops are in a succulent stage of growth, the roots and tops again are high in water content and low in dry matter. This condition is again reversed as the plants approach fall or early winter dormancy.

The relation between the total carbohydrates and nitrogen in the tops of the plants is different in each of the consecutive growth stages. This relation between total carbohydrates and nitrogen is similar in the roots and tops in each of the different growth stages during the season. The total water soluble nitrogen and insoluble nitrogen are found in different proportions in each of the different stages of growth, but these proportions are very similar in the tops and roots at these various periods of growth. This similarity between the carbohydrates and total nitrogen and soluble and insoluble nitrogen in the tops and roots at different stages of growth does not mean that the same ratio exists between these compounds in these parts, but rather that a similar variation in the percentage and quantity of these compounds is shown in the tops and roots from one growth stage to another.

DISCUSSION

The variation in the percentage and quantity of root reserves in alfalfa in Experiments I and II and its apparent direct relation to top growth shows the dependence of one upon the other. The decrease in root reserves in early spring is closely associated with the early top and root growth of the plants. The percentage and quantity of these reserves are again replenished when the top growth is of a sufficient size and maturity to elaborate organic foods in excess of those needed for growth and maintenance. These excess foods are translocated to and stored in the roots for the production of new growth. The gradual decrease in successive yields of top growth from plants cut frequently in the succulent stages of growth in Experiments I and II and the corresponding decrease in the percentage and quantity of root reserves as compared to the plants cut in the more mature stages lend weight to the contention that yield and vigor of top growth are dependent upon the percentage and quantity of reserves in the roots. The frequent cutting of the tops before they are of sufficient size and maturity to replenish the losses sustained by the roots not only results in loss of the percentage and quantity of root reserves and the ability of the plants to produce new top growth, but root development is retarded as a result of the continued production of new top growth (Tables 1 to 6).

The differences in percentage and quantity of reserves and the weight of the roots, resulting from the top cuttings, are much more pronounced in Experiment II than in Experiment I. This difference results from the greater number of cuttings of the plants in the succulent stage of growth in Experiment II, and also from the time of digging. Roots of the plants in Experiment II cut in the more mature stages were not dug until fall dormancy developed almost three months after the cutting in the semi-mature stage of growth (second), while the roots from plants cut in the more mature stages in Experiment I were dug immediately after the cutting in the semi-mature stage.

There is relatively little difference in the percentage of reserves resulting from the different cuttings in Experiment I, due to the fact that the new top growth cut in a semi-mature stage when the roots were dug apparently caused a marked decrease in the percentage of root reserves. In Experiment II the plants were cut at this stage but were not dug until fall, fully three months later, when the loss of reserves produced by the semi-mature growth may have been for the most part replenished.

The differences in the weights of the roots of plants resulting from the different cutting treatments are also more pronounced in Experiment II than in Experiment I. These differences may also be attributed to the fact that the plants in Experiment I were dug on July

14, 1923, after the third cutting in the succulent stage and that in the semi-mature stage of growth. The retardation of growth and probably the decrease in weight of roots, resulting from the cutting in the seed-pod stage and the production of the new top growth after this cutting, caused the roots of the plants cut in the more mature growth stages in Experiment I to weigh considerably less when dug than similar plants of Experiment II cut at similar growth stages but not dug until fall dormancy developed fully three months later. The digging of these plants in Experiment II in late fall gave the roots of the plants ample time to recover from the effects of the cutting in the seed-pod stage and the production of the new top growth which followed. The larger top growth produced during this time for photosynthetic activity and the organic foods elaborated in excess of those needed for maintenance brought about increased root growth and storage of root reserves. Plants cut frequently in the succulent stages of growth go into winter dormancy with a low percentage and quantity of organic root reserves and with a high moisture content, which probably has an important relation to their susceptibility to winter injury.

A study of the alfalfa roots and tops in Experiment III at the various periods of growth during the season substantiates many of the results found in Experiments I and II. The spring condition of the roots on April 13, 1924, shows a fairly high percentage and quantity of reserves. That these reserves in the roots contribute to the early top and root growth of the plants is evidenced here by their condition on May 26, 1924, when the plants showed a vigorous succulent top growth. At this time, the increase in the green and dry weights of the roots and tops is accompanied by a marked decrease in the percentage and quantity of total sugars, starches, and hemicelluloses. Whether this drain of reserves from the roots caused a decrease in the weight of the roots in their early growth cannot be determined from data given but is probable, judging from the decreased weight of the roots in the second succulent stage several weeks after the cutting in the seed-pod stage of growth. The soluble starches and dextrins are assumed to be transition forms of carbohydrates, i. e., starches change to these forms in the process of forming sugars and sugars form soluble starches and dextrins in changing to starches. The percentage of these compounds (soluble starches and dextrins) varies with the rate of transformation (starches to sugars and sugars to starches). At what exact stage of growth of the plant the root reserves are lowest and when replenishing of the losses sustained by the roots begins is difficult to state from the data given.

Analyses of roots dug at shorter intervals during the early growth period of the plants are needed to determine this more definitely. It is evident, however, that the percentage and quantity of reserves and the percentage of dry matter in the roots increase rather steadily with the advancing maturity of the top growth. The percentage of total carbohydrate reserves in the roots is highest in the full-bloom stage. In quantity, all carbohydrate reserves are highest in the seed-pod stage of growth.

The enormous decrease in the size and weight of the roots five weeks after the plants were cut in the seed-pod stage is not entirely accounted for from the data given. The vigorous succulent top growth of the plants caused approximately a 50% reduction in the percentage of all carbohydrate reserves in the roots. The top growth produced is approximately six times that produced over approximately an equal period of time in the early part of the growing season before the roots attained the size and weight prevalent at the seed-pod stage of growth and the total carbohydrates are over 20 times as great in quantity. This apparently emphasizes the fact that the amount of top growth is dependent not only on the percentage but also on the quantity of reserve materials in the roots. Whether injury to the plants, such as cutting the tops when the plants are in a non-vegetative stage of growth, is a factor in reducing the weight of the roots through increased respiration and bleeding of the plants, is not certain, but the enormous decrease in root weight here indicates such a possibility. This is further substantiated by the fact that the new growth after the cutting on August 8, 1924, caused a comparatively greater loss of root reserves than early spring top growth (Table 4).

A marked increase is found in the quantity of all carbohydrate reserves as the plants approach fall dormancy. The seasonal variation of the total sugars differs considerably from that of the other carbohydrates. The marked drop in the spring with respect to the sugars may be explained by loss through respiration and translocation to the new top growth. After the assimilatory activity of the leaves is sufficient for growth and maintenance, the percentage of sugars does not show a marked increase but remains almost constant during the growing season. This may be the result of increased respiration of the plants and the translocation of sugars to the roots for the formation of starch and hemicelluloses. The rapid accumulation of sugars in the roots in the fall is associated with lowered respiration of the plants, decrease in starch, and partial conversion of starch to sugar. This condition seems to continue until spring, judging from the low percentage of starch and high percentage of sugars in the roots when spring growth begins.

The percentage of total nitrogen in the roots follows a similar trend as does that of the carbohydrates through the various stages of growth, decreasing with the initiation of new top growth and increasing in quantity as the plants reach maturity. The percentage of dry matter in the roots coincides with that of the reserves, decreasing with the initiation of new top growth and increasing as the plants approach maturity. The relation between the total nitrogen and total carbohydrates is different in the tops of the plants in each of the different growth periods. This is in agreement with the surmise of Kraus and Kraybill (3) and other workers (4, 5) on the nitrogen and carbohydrate relation in plants. This carbohydrate nitrogen relation in the roots at each of the different growth stages is similar to that of the tops, and likewise, varies with them from one period of growth to another.

The soluble and insoluble forms of nitrogen are found in different proportions in each of the different growth stages, but these proportions are similar in the tops and roots in each of these different growth stages. Whether this difference in proportions of soluble and insoluble nitrogen in the roots and tops of alfalfa at different stages of growth is directly associated with its growth responses is uncertain, but it seems very likely that such is the case.

No flowers or seed pods were found on the plants of the second growth after the cutting in the seed-pod stage. The total nitrogen and total carbohydrates in the roots and tops during the latter part of the growing season show a somewhat different relation to each other than is found at the full-bloom stage. A higher percentage of nitrogen and lower percentage of carbohydrates is shown. This may be due to variation in light and soil conditions from that which prevailed during the earlier part of the growing season. Although no flowering or seed-pod formation took place, the losses in reserves sustained by the roots from the initiation of new growth appear to have been replenished to a considerable extent. This is undoubtedly due to the increase in top growth and photosynthetic activity elaborating organic foods in excess of those needed for maintenance and growth and translocating them to the roots. What percentage and quantity of reserves will be found in the roots at any particular growth stage apparently depends upon the environmental conditions for plant growth. When the soil contains sufficient moisture and available nitrates for plant growth, a vigorous vegetative growth will follow, resulting in a large top growth. This large increase in top growth with increased leaf area for photosynthetic activity results in greater elaboration of carbohydrate foods in the plant and hence a wide carbohydrate nitrogen relation follows which is associated with reproduction in or flowering of the plants. On the other hand, if the soil becomes low in moisture and available nitrates during the early growth stages, the nitrogen in the plant will become low in relation to the carbohydrates as a result and flowering will take place before sufficient top growth has been produced to replenish the loss of reserve foods sustained by the roots in the production of early top growth, and hence the roots are in a poor condition to produce new growth if the plants are cut at this time (bloom stage). Thus, it seems apparent that the quantity of reserves in the roots for the initiation of new top growth depends to a great extent upon a favorable plant environment for the production of a large vegetative top growth before bud or flower formation takes place. This brings about the elaboration of a large quantity of organic foods in excess of those needed for growth and maintenance to be translocated to the roots and used later for new growth after the tops are cut. Any stage of growth, whether flower bud, bloom, or seed-pod, indicates only the general relative composition of the plant and not the quantity of reserves in the roots (18). The quantity of reserves in the roots can be better ascertained by the quantity and maturity of the top growth on the plants.

SUMMARY

Alfalfa plants were cut in the succulent and more nearly mature stages of growth during the summer of 1923 and results of such cuttings on the reserves in the roots determined. The distribution of some of the organic foods in alfalfa plants at various stages of growth was determined from the analysis of groups of plants dug at different growth stages during 1924.

The initiation of new top and root growth in early spring is produced at the partial expenditure of the reserve organic foods in the roots. A certain amount and maturity of top growth are essential before the replenishment of the reserve foods of the roots takes place. The quantity of these carbohydrate and nitrogenous reserves is highest when the tops have attained a maximum growth and are in the advanced stages of maturity.

Cutting alfalfa frequently in the immature stages of growth causes a continuous reduction of the organic root reserves without replenishment of the same for subsequent growth, retards the increase in the size and weight of the roots, and decreases the vigor and production of new top growth.

Alfalfa plants cut frequently or late in the season in the succulent growth stages go into winter dormancy low in organic root reserves, high in moisture, and may suffer severe winter injury, while plants cut in the mature growth stages and not late in the season go into winter dormancy high in organic root reserves, low in moisture, and appear much more resistant to winter injury.

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STUDIES ON THE GROWTH OF ALFALFA AND SOME PERENNIAL GRASSES[1]

W. B. ALBERT[2]

It has long been a matter of common knowledge that the extent of the top growth of plants is intimately associated with the extent of their root development, and that plants are able to store organic foods which the plant may subsequently use. Only recently, however, have some of the specific aspects of these relations been studied and some of the results of these investigations embodied in agricultural practice.

Kraus and Kraybill (3)[3] were the first workers to call attention to the relationship existing between the carbohydrate reserves and nitrogenous compounds of the tomato plant with its behavior in regard to vegetative growth and fruitfulness.

Subsequently, work by Reid (5) brought out the fact that a low nitrogen content associated with a high carbohydrate content of the stem promoted a vigorous root growth in tomato cuttings. Definite responses in root and shoot growth would result when the existing relations of nitrogen and carbohydrates were altered.

At Missouri (8) the importance of a high content of reserves to the timothy plant had already been shown. It had been established that the cutting of timothy at immature stages reduced the storage of organic reserves and inhibited corm development. This reduced the longevity of the field as well as lessening the yields and thickness of stand. It was suggested that the initial top growth of timothy was made at the expense of reserves previously stored in the corms and that when timothy was cut at relatively immature stages the utilization of these reserves for top growth was very rapid. Early cutting, therefore, gave little opportunity for storage of such reserves as might be required for a maximum amount of future growth.

Remy (6) studied the absorption of mineral nutrients by alfalfa and other plants. A decrease in the amount of minerals present in the root at the beginning of top growth in the spring and early summer was found to occur.

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[3] Reference by number is to "Literature Cited," p. 654.

Whiting and Richmond (9) studied the composition of biennial sweet clover at various stages in its life history with regard to its mineral constituents. It was found that in the fall of the first year a storage of nitrogen, potassium, sulfur, and phosphorous occurred. At the beginning of top growth in the spring the percentages of these elements appeared to increase slighlty after which a rapid decrease occurred, due to translocation of these substances into the rapidly growing tops. In some instances root development was found to occur in early spring before the beginning of top growth.

That specific gravity is a useful means of measuring the reserve content of alfalfa roots is reported by Wahlen (7). He found that the specific gravity of alfalfa roots decreased after cutting of the top growth and then again gradually increased until a maximum was reached. As measured by specific gravity, the greatest storage in alfalfa roots occurred during the third year, after which a gradual decline in the ability of the roots to store reserves set in.

The results of experiments conducted over a period of eight years at Kansas (2) indicate an important relation of reserves to cutting treatments. It was found that when alfalfa was cut at stages less mature than full bloom the longevity of the stand and the yields were appreciably reduced. Plants cut at the full-bloom and seed-pod stages were capable of maintaining themselves over a considerable period of years. Cutting at immature stages thinned the stand and lowered the yields.

Somewhat similar results were obtained in trials conducted at the Wisconsin Experiment Station. Nelson (4) found that frequent cutting resulted in lowered yields, lessened the vigor of growth, retarded root development, and resulted in considerable differences in reserve content of alfalfa plants, as compared to plants cut at mature stages. The growth response of the plant after cutting was directly influenced by the amount of organic reserves present in the root. A correlation between frequent cutting, large amount of winterkilling, weed infestation, and a slow recovery after cutting was also found to be true.

Leukel[4] compared the effects of frequent cutting at different stages upon the deposition and utilization of reserves in alfalfa. Considerable reductions in water soluble constituents of the root, correlated with small size and reduction of reserves in the roots of plants cut frequently, was found to exist. A tendency towards a uniform relationship between the water soluble and insoluble nitrogen at different stages of growth was manifested.

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[4] See preceding paper in this JOURNAL.

This paper attempts to correlate the experimental results obtained in a study of the carbohydrate and nitrogen relationships in alfalfa, bluegrass, and redtop with their general behavior under varying field conditions. The work has been conducted with the following points of view in mind:

1. Behavior of alfalfa, redtop, and bluegrass plats under varied stages and frequencies of top removal, with regard to the general condition, yield, relative amount of root development, weed encroachment, and winterkilling.
2. Differences in carbohydrate and nitrogen content of alfalfa plants under varied cutting treatments.
3. The location, storage, and utilization of organic reserves in the alfalfa plant.
4. The effect of varying carbohydrate and nitrogen relations upon the relative structure of different tissues of the root and stem.

LABORATORY METHODS

During 1925, samples of 50 plants, including both tops and roots to a depth of 7 inches or more, were dug from the plats that were to be cut on that day. These plants were taken to the laboratory, the soil removed by washing with tap water, the tops cut off, and the roots cut to a uniform length not exceeding 7 inches. Green weights of both the tops and the roots were obtained. The tops and roots were then preserved separately for future chemical analysis by covering with 95% alcohol, adding a little calcium carbonate to neutralize any acids present, and then boiling on a water bath from one-half to one hour.

METHODS OF CHEMICAL ANALYSIS

The alcohol was drained from the samples that had been preserved in the manner described above and the material and the alcohol extract dried separately in an oven at about 65°C to constant weight. The alcohol extract was taken up with hot water, diluted to volume, and analyses for reducing sugars, total sugars, and total nitrogen were obtained from aliquot portions.

The dry material was first coarsely ground and then ground in a pestle mill until either the entire sample or a representative portion thereof passed through an 80-mesh sieve. Total nitrogen and carbohydrate analyses were made of this finely ground material, using the methods described on the following pages. Ether extracts of the dry material were not taken as they were found to be uniformly small and had no influence upon the carbohydrate analyses. Duplicate analyses were made of each sample. The maximum variation allowed between the duplicates was 10%. Most samples, however, checked much more closely. Total nitrogen in all cases was determined according to the Kjeldahl method modified to include nitrates.

CARBOHYDRATE ANALYSES

In all cases the reducing power of the solutions was determined by the iodometric method of Schaffer and Hartman (10). The method of procedure follows.

Reducing sugars.—A 2-gram sample of the finely ground plant material was refluxed with 90% alcohol, filtered, and the filtrate evaporated to dryness or until alcohol free, at a temperature of from 65° to 75°. About 75 to 100 cc of water were then added. Neutral lead acetate was then added until no further precipitation occurred. After filtering and washing, sodium sulfate and sodium carbonate were used to delead after which the solution was neutralized and the reducing power of an aliquot determined.

Total sugars.—An aliquot of the above solution was acidified to a concentration of 2.5% HCl, hydrolyzed on a sand bath for three-fourths of an hour, neutralized, and the reducing power determined as above.

Dextrins and water soluble starch.—The residue from the original alcohol extraction was washed into a flask with about 75 to 100 cc of cold water. This was allowed to stand for at least 12 hours at room temperature and then filtered and washed. The residue was used for starch analysis. The filtrate was acidified to a concentration of 2.5% HCl and hydrolyzed for two and one-half hours on a sand bath. The solution was then neutralized, diluted to volume, and the reducing power of an aliquot determined as previously mentioned.

Starch.—The residue was washed into a beaker, boiled from one-half to one minute, and from 5 to 10 cc of fresh saliva added. When the solution was starch free as indicated by the iodine test, the solution was filtered, acidified to 2½% HCl, and hydrolyzed for three-fourths of an hour, after which the reducing power of an aliquot was determined in the usual manner.

Hemicelluloses.—The residue from the starch digestion was washed into a flask with 2½% HCl and hydrolyzed for two and one-half hours on a sand bath. The contents of the flask were then filtered, washed, neutralized, diluted to volume, and the reducing power of an aliquot determined as previously described.

PRESENTATION OF DATA

In the presentation and discussion of the following data the term "reserve carbohydrates" will be used frequently. Only the sugars, dextrins, starches, and hemicelluloses, as determined by the methods of analysis previously discussed, are considered reserve carbohydrates and classed as such throughout this discussion.

EXPERIMENT I

During the summer of 1922 and up to July 1923, a piece of land was summer fallowed. In the summer of 1923 two long strips of this land were graded and rounded off with a road grader in such a manner as to insure surface runoff of water from these strips into the adjacent alleys. On July 23, 1923, one of these strips was sown to Grimm alfalfa and one to South Dakota common alfalfa, the alleys being sown to white clover.

Under the favorable growing conditions of 1923 an exceptionally uniform and vigorous stand of alfalfa resulted in the fall, which, except for the removal of weeds by pulling in the latter part of September, received no further treatment that year. The two strips came through the winter without serious injury (Table 1), and in the spring of 1924 they were divided into plats. The Grimm plats used in this trial were numbered 401 to 411 and the corresponding plats of South Dakota common alfalfa were numbered from 501 to 511. The Grimm plats were one one-hundreth and the common were one-hundred and fiftieth acre in area. It was believed that the larger number of small sized plats permitting replications would yield more trustworthy results than larger plats with fewer replications. The replicate plats were arranged so that all cutting treatments would be in adjacent plats somewhere in the series. During the season of 1924 both Grimm and common plats received the following cutting treatment:

Two cuttings in full bloom (3 plats)
Two cuttings in full bloom and the fall growth removed (2 plats)
Three cuttings in tenth bloom (3 plats)
Three cuttings in tenth bloom and the fall growth removed (3 plats).

The season of 1924 was characterized by a cool summer with an abundance of rainfall, and a warm, sunny fall with few severe frosts until about November 15. In spite of this, the amount of aftermath which was removed from some of the plats in the latter part of November, 1924, was not very large.

As soon as possible after cutting, the weight of the green material of each plat was obtained. A representative sample of from 2 to 5 pounds of this green material was then taken, dried in an oven, and the percentage of moisture calculated. This percentage of moisture was then used in calculating the yield of dry matter from each plat.

During 1924 and 1925 each plat received the same cutting treatment. No manure or fertilizer was applied to these plats during the period of the experiment.

As has already been mentioned, the general condition of the stand in both the common and the Grimm plats was one of uniform excellence in the fall of 1923. The seedling plants passed through the winter with practically no winter injury except in one of the three plats (511) cut in tenth bloom and which had had its fall growth removed (Table 1). The relatively high percentage of winterkilling in this plat can probably be explained by its location, which was on the lower end of the field where the drainage was such that the plat was kept in a relatively wet condition during the period of varying temperatures just prior to growing weather that is often so critical.

TABLE 1.—*Percentage of dead plants in plats of Grimm and South Dakota common alfalfa.*

Cutting treatment	Number of plats	Percentage of plants dead					
		April 22, 1924		April 9, 1925		April 28, 1926	
		Grimm	Common	Grimm	Common	Grimm	Common
Full bloom, 2 cuttings.	3	0	1	12.3	23.7	10.6	30.0
Tenth bloom, 3 cuttings.	3	0	0	29.0	45.3	31.3	75.0
Tenth bloom, 3 cuttings and fall growth removed	3	2.7	19.0	35.0	84.0	34.0	97.0
Full bloom, 2 cuttings and fall growth removed	2	0	6.5	27.5	82.5	20.0	90.5

The winter of 1924–25 was quite severe as far as its effect on alfalfa was concerned. A large amount of winterkilling occurred throughout Wisconsin, due perhaps to a general lack of a protective covering of snow. This climatic situation was such as to bring about striking results with common alfalfa in relation to the effect of cutting treatments on the percentage of winterkilling. Table 1 shows the percentage of winterkilling of the alfalfa in the spring of 1924 when there was no effect from previous cutting, in 1925 after one year of the cutting treatments indicated, and in 1926 after two years of such cutting treatments.

As might have been expected, South Dakota common alfalfa suffered very much more severely from winter injury with all cutting treatments than did the Grimm. The removal of even small amounts of late fall growth increased the winter injury of both varieties to a marked degree. The alfalfa cut twice in full bloom was the least susceptible to the hazards of winter weather.

YIELDS

The yields of alfalfa in pounds of oven-dried hay an acre for each type of cutting treatment are presented in Table 2. It will be noted that in 1924 the plats cut at tenth bloom and those that had the fall growth removed outyielded those cut at full bloom. In 1925, after the second year of cutting the situation existing in 1924 was reversed. The Grimm plats cut twice at full bloom outyielded those cut three times at tenth bloom by 638 pounds of hay an acre, or nearly 11%. In the common plats this situation was intensified, and the plats cut at full bloom outyielded those cut at tenth bloom by 1,034 pounds an acre, or about 23%. The removal of from 300 to 700 pounds of dry hay an acre in the late fall of 1924 practically ruined a good stand of the common alfalfa. The close association of winter hardiness with yields in alfalfa is indicated by the marked responses of common alfalfa to unfavorable cutting treatments in comparison with Grimm. However, in 1924 the yields of Grimm alfalfa were also from 10 to 25% larger than with common.

WEED ENCROACHMENT

There were no appreciable quantities of weeds present in the plats during 1924 and no weed determinations were made. After the heavy winterkilling of 1924-25 encroachments of weeds occurred in many of the plats during the cutting season. Wherever such weeds were present in appreciable amounts, determinations were made at each time of cutting. The larger portion of the foreign plants present in the plats in 1925 consisted of bluegrass. The percentage of weeds present in the hay from each plat of both the common and the Grimm alfalfa and the averages for each series of plats are presented in Table 2.

It will be noted that in the Grimm plats the variation in percentage of weeds in the hay between each series of cutting treatments was not very great in comparison with the common plats where considerable variations in the percentages of weeds were found. Such plats cut three times and having the fall growth removed had 38.8% of weeds in the hay as contrasted to 23.4% in similarly cut plats where the fall growth was not removed.

While the amount of weeds was generally correlated with the amount of winterkilling, such cutting treatments as affected the vigor of growth also tended to influence the weed content of the hay.

TABLE 2.—*Yields per acre of weed-free, oven-dried alfalfa hay of Grimm and South Dakota common receiving various cutting treatments.*

Cutting treatment	Number of plats	Yield per acre of pure alfalfa hay in pounds 1924 Grimm	1924 Common	1925 Grimm	1925 Common
Full bloom, 2 cuttings	3	8,300	6,603	6,596	5,396
Tenth bloom, 3 cuttings	3	9,328	7,858	5,958	4,362
Tenth bloom, 3 cuttings and fall growth removed	3	9,663	8,653	6,539	2,843
Full bloom, 2 cuttings and fall growth removed	2	8,960	7,603	7,395	3,950
Percentage of Weeds in Alfalfa Removed from Plats					
Full bloom, 2 cuttings	3	none	none	9.3	12.0
Tenth bloom, 3 cuttings	3	none	none	17.6	23.4
Tenth bloom, 3 cuttings and fall growth removed	3	none	none	11.6	38.8
Full bloom, 2 cuttings and fall growth removed	2	none	none	8.4	12.7

The lack of uniformity in the distribution of weed seeds in the soil and many other factors may also cause variations in the presence of weeds in alfalfa hay.

CHEMICAL DATA

All of the analyses were made on Grimm plants. The first sample was dug on Nov. 28, 1923, and consisted of 10 roots which were oven dried. The samples dug on Dec. 2, 1924, and in 1925 were all alcohol preserved. With the exception of the seedling plants of 1923, all samples consisted of 50 roots and included, when present, the top growth of these 50 roots. No effort at selection of plants was made, except that only apparently healthy and vigorous plants were taken.

Table 3 shows the results of the analyses of the roots of plants cut at the full-bloom and tenth-bloom stages. During the growing season there is a pronounced tendency for the roots of the plants cut at full bloom to be higher in percentage and amount of dry matter than the roots of the plants cut at tenth bloom. Towards the latter part of the season there is likewise a tendency for an increase in percentage of nitrogen in the roots of plants cut at full bloom as compared with the roots of the plants cut at tenth bloom. The roots of the plants cut at full bloom invariably contain a higher percentage of total carbohydrates than do those cut at tenth bloom. This difference, however, is not very large, being in most cases between 3 and 4%. These differences are considerably accentuated when total quantities instead of percentages are considered. This will be discussed later.

The differences between the top growth of plants cut at full bloom and at tenth bloom are shown in Table 4. The percentage of total carbohydrates is appreciably greater in the top growth of plants cut at full bloom, while the percentage of total nitrogen is lower. It will be observed that each type of carbohydrate varies more or less and that absolute conclusions cannot be drawn. Certain general tendencies are apparent, however, and may be stated as

TABLE 3.—*A detailed comparison of the percentage and quantity of organic reserves in roots of alfalfa plants cut in tenth- and full-bloom stages of growth.*

Analyses expressed on dry basis and all carbohyrates expressed in terms of glucose.

Stage of cutting in 1924 and 1925	Number of cuts	Samples dug								
		Nov. 28, 1923	Dec. 2, 1924	April 9, 1925	June 13, 1925	June 23, 1925	July 21, 1925	Aug. 18, 1925	Sept. 16, 1925	Nov. 16, 1925
Percentage Dry Matter in Roots										
Full bloom	2	——	30.3	30.9	——	39.4	——	43.0	——	34.4
Tenth bloom	3	——	31.7	26.3	32.2	——	35.4	——	37.5	34.1
Percentage Total Carbohyrates in Roots										
Full bloom	2	31.26	39.28	30.62	——	43.15	——	37.42	——	33.97
Tenth bloom	3	31.26	34.15	30.06	40.50	——	34.30	——	30.90	30.87
Percentage Total Nitrogen in Roots										
Full bloom	2	3.74	3.24	3.78	——	2.20	——	2.77	——	3.08
Tenth bloom	3	3.74	3.24	3.75	2.59	——	2.50	——	2.85	2.88
Percentage Reducing Sugars in Roots										
Full bloom	2	1.00	2.95	0.84	——	3.38	——	3.60	——	1.53
Tenth bloom	3	1.00	2.17	0.94	4.76	——	3.12	——	2.55	0.75
Percentage Total Sugars in Roots										
Full bloom	2	7.56	13.85	9.03	——	9.83	——	9.65	——	12.02
Tenth bloom	3	7.56	11.73	9.77	11.73	——	9.55	——	7.30	13.18
Percentage Dextrins and Soluble Starch in Roots										
Full bloom	2	2.06	2.82	1.86	——	3.72	——	3.02	——	1.60
Tenth bloom	3	2.06	2.54	1.74	3.87	——	2.95	——	3.20	0.87
Percentage Starch in Roots										
Full bloom	2	9.84	8.16	4.08	——	14.65	——	11.60	——	7.50
Tenth bloom	3	9.84	5.68	3.45	9.60	——	9.85	——	9.80	3.52
Percentage Hemicelluloses in Roots										
Full bloom	2	11.8	14.45	15.65	——	14.95	——	13.15	——	12.85
Tenth bloom	3	11.8	14.20	15.10	15.30	——	11.95	——	10.60	13.30
Dry Weight of 50 Roots in Grams										
Full bloom	2	——	59.2	61.4	——	133.0	——	151.5	——	171.5
Tenth bloom	3	——	57.7	45.7	101.5	——	96.5	——	148.5	123.0
Grams Total Carbohydrates in 50 Roots (Expressed as glucose)										
Full bloom	2	——	23.25	18.80	——	57.39	——	55.69	——	58.26
Tenth bloom	3	——	19.70	13.74	41.11	——	33.10	——	45.89	37.97
Grams Total Nitrogen in 50 Roots										
Full bloom	2	——	1.92	2.32	——	2.93	——	4.20	——	5.28
Tenth bloom	3	——	1.87	1.71	2.63	——	2.41	——	4.23	3.54

follows, although exceptions in any particular case may be present.

1. The percentages of reducing sugars vary greatly in both roots and tops from time to time. From the data of this experiment no specific conclusions concerning their rôle in the plant growth can be drawn.

TABLE 4.—*A detailed comparison of the chemical composition of the top growth of plants cut at the full-bloom and tenth-bloom stages.*

Carbohydrate analyses expressed on dry basis and in terms of glucose.

Cutting treatment	Tenth bloom, 3 cuts	Full bloom, 2 cuts	Tenth bloom, 3 cuts	Full bloom, 2 cuts	Tenth bloom, 3 cuts
Cutting date	June 13, 1925	June 23, 1925	July 21, 1925	Aug. 18, 1925	Sept. 16, 1925
Dry weight in grams of 50 tops	126.5	223.0	122.0	116.0	94.5
Percentage dry matter	25.5	30.6	30.6	36.5	30.2
Percentage total nitrogen	3.34	3.01	2.90	2.78	3.45
Percentage reducing sugars	0.66	1.81	1.13	1.43	0.39
Percentage total sugars	2.84	3.83	4.10	3.55	2.48
Percentage dextrins and water soluble starch	1.12	1.33	0.87	1.30	0.69
Percentage starch as glucose	none	2.35	1.97	1.65	none
Percentage hemicellulose	16.00	14.80	12.20	16.65	12.45
Total carbohydrates	19.96	22.31	19.14	23.15	15.62

2. The percentage of total sugars in the roots is at a maximum in late fall. There are no significant and consistent differences in the percentage of total sugars between the plants cut at the full-bloom and tenth-bloom stages, in either the tops or the roots.

3. The dextrins and water soluble starches, which may be regarded as transition products of starch, do not vary greatly in either roots or tops and probably not significantly.

4. The percentage of starch in the roots seems to be at a maximum during the summer, and may be greater than the percentage of sugars. In the fall the percentage of sugars increases and the percentage of starch declines. Starch seems to be stored in the top growth only after it has become relatively mature.

5. There appear to be no consistent or significant variations in the percentages of hemicelluloses. It is probable that the methods in use for their estimation require modification before analyses that are comparable to the situation existing in the plant can be obtained.

If the samples obtained from June 13 to Nov. 16, 1925, of each type of cutting treatment are averaged and compared with each other as in Table 5, it will be noted that there was a considerable increase in weight of the roots of plants cut at full bloom in contrast to roots of plants cut at tenth bloom. The average differences in the

TABLE 5.—*Comparison of the weighted average of samples of alfalfa plants cut at tenth-bloom and full-bloom stages from June 13 to Nov. 16, 1925.*

Description of sample	Number of plants in sample	Number of samples averaged	Average percentage of dry matter	Average dry weight in grams per sample	Average percentage total nitrogen	Average percentage total carbohydrates
Full bloom, roots	50	3	38.4	152.0	2.72	37.8
Tenth bloom, roots......	50	4	34.9	117.4	2.72	33.6
Full bloom, top growth ..	50	2	32.4	169.5	2.92	22.6
Tenth bloom, top growth	50	3	28.2	114.3	3.21	18.5

percentages of dry matter ranged from 3.5% in the roots to 4.2% in the top growth. The average percentage of nitrogen was the same in the roots, but, as has been mentioned, was greater in the top growth of the plants cut at tenth bloom. The percentage of total carbohydrates averaged 4.2 more in the roots of the plants cut at full bloom.

If a value of 100 be assigned to the total weight in grams of the roots and tops, to the total nitrogen and reserve carbohydrates of the roots and tops, and to the average percentage of dry matter of plants cut at full bloom and if this is compared with the roots and tops of plants cut at tenth bloom, the relations shown in Table 6 will be obtained. In each comparison, the roots of plants cut at tenth bloom are lower in value than the roots of plants cut at full bloom. The nitrogen present in the tops of plants cut at tenth bloom exceeds by 11% the nitrogen present in the tops cut at full bloom.

TABLE 6.—*Comparison of reserves present in 50 plants in 1925 with relation to each cutting stage.*

Samples	Number of samples	Percentage of dry matter	Total weight in grams	Percentage total nitrogen	Percentage total carbohydrates
Full bloom, roots	3	100	100	100	100
Tenth bloom, roots	4	90.8	77.2	77.2	68.6
Full bloom, tops	2	100	100	100	100
Tenth bloom, tops	3	87.0	101	111	82.8

TABLE 7.—*Calculated yield in pounds per acre of carbohydrate and nitrogen compounds produced by each series of plats in 1925.*

Stage of cutting	Number of cuts	Pounds total nitrogen in tops harvested in 1925	Pounds total carbohydrates in tops harvested in 1925	Yield of carbohydrates and nitrogen in relation to each treatment	
				Nitrogen	Carbohydrates
Full bloom	2	193.8	1,488.6	100	100
Tenth bloom	3	189.5	1,116.3	97.7	74.9

Since the total yield of dry matter per plat was obtained at each time of cutting, the total amounts of nitrogen and carbohydrates present in the top growth of each cutting series can readily be computed to an area basis. Table 7 represents this calculation based on the average yields of the plats cut at full bloom and tenth bloom. The plats cut at full bloom have 372.3 pounds an acre more reserve carbohydrates, or 25.1% more, than the plats cut at tenth bloom. It will be observed also that the yield of total nitrogen of the plats cut at full bloom exceeds that obtained from the plats cut at tenth bloom by 4.3 pounds an acre, or by 2.3%. In Table 6 the total nitrogen present in the tops of 50 plants cut at tenth bloom was 11% more than that present in the tops of 50 full-bloom plants. Table 7 as compared to Table 6 is probably the more representative of conditions existing in the plats, because it is based on actual yields. The differences between the roots must be calculated on a basis of equal numbers of roots, as it was impractical to collect a representative sample of roots on an area basis.

EXPERIMENT II

On July 23, 1924, a strip of land previously graded so as to insure surface runoff of water was sown to Grimm alfalfa. In the fall of 1924 there was a uniform, vigorous stand of alfalfa that lived through the rather severe winter of 1924-25 without suffering any noticeable winterkilling. In the spring of 1925 the plats were staked and numbered from 601 to 615. Because of erosion, plats 608, 609, and 611 were not harvested and, therefore, play no part in the following discussion.

A cutting system designed to produce more extreme contrasts than that used in Experiment I was introduced. The following cutting treatments were given:

Plats 601 and 615 received no cutting.

Plats 603 and 613 were cut twice at the full-bloom stage of growth.

Plats 605 and 614 were cut at the seed-pod stage of growth, which was from 21 to 28 days after the harvesting of the full-bloom plats.

Plats 604 and 612 were cut when the first buds could be observed. This stage of growth is named "flower-bud" in this experiment.

Plats 602 and 606 were cut when the top growth was about 8 to 10 inches in height. These plats will hereafter be referred to as the "succulent" plats.

Plats 607 and 610 were cut when the top growth was 3 to 5 inches in height. A lawnmower equipped with a grass-catching attachment was used for the cutting. No yield records for these plats were kept. This type of cutting will be referred to as "rosette stage" in the following discussion.

Except as noted in the case of the plats cut at the rosette stage, the method of harvesting was similar to that used in Experiment I.

The yields per acre of dry alfalfa hay for these differently cut plats are given in Table 8. The plats cut four times at the flower-bud stage and those cut six times at the succulent stage yielded nearly as much hay per acre as the plats cut twice at the full-bloom stage of growth. The lowest yields were obtained from the plats cut at the seed-pod stage which yielded 1,565 pounds of dry hay less than plats cut in full bloom. This decrease is partially explained by the loss of leaves caused by grasshoppers and losses in harvesting due primarily to maturity. The general appearance and behavior of the plats under these systems of treatment were interesting. As was to be expected, the plats cut at the full-bloom and seed-pod stages of growth sent forth vigorous and sturdy shoots after each cutting.

The plats cut at the flower-bud stage also made a rapid and vigorous recovery after the first and second cutting. However, the growth made after the third and fourth cutting was rather spindling and weak and its rate of growth was very slow as compared to the plats cut at full bloom. A rapid and vigorous initiation of new growth after the first two cuttings was likewise observed in the plats cut at the succulent stage. After that, however, the stems produced by the plants were slender, the rate of growth was slow, and weeds began to appear in the plats. The greater number of the alfalfa plants present in the plats cut at the rosette stage were gradually weakened and killed during the first five of the nine cuttings and weeds took possession of the plats due to the thinning of the stand and the very slow recovery of growth after each cutting.

LABORATORY DATA

Samples of 50 plants were taken at each cutting date, preserved in alcohol, and subsequently analyzed, following the procedure described for Experiment I.

The detailed results of the analyses of the plants used in this experiment show the same general tendencies already discussed in Experiment I, and are, therefore, omitted. The history of each series of differently cut plants at each cutting date in regard to reserve carbohydrates and total nitrogen of the roots and tops and the change in weight of samples of 50 roots is shown in Figs. 1, 2, and 3, respectively.

A comparison of the percentages of total carbohydrate reserves and the total nitrogen of samples representing each cutting treatment can be made by referring to Fig. 1. This illustrates the percentage of total nitrogen and reserve carbohydrates of all series at each time of cutting. It should be emphasized here that the straight

TABLE 8.—*Yields in pounds per acre of weed-free, oven-dried alfalfa hay from plats 601 to 615 during 1925.*

Plat	Cutting	First cut		Second cut		Third cut		Fourth cut		Fifth cut		Sixth cut		Total
No.	treatment	Date	Yield	Date	Yield	Date	Yield	Date	Yield	Date	Yield	Date	Yield	yield
605	Seed pod	July 13	4,540	Sept. 17	2,520	——	——	——	——	——	——	——	——	7,060
614	Seed pod	July 13	3,840	Sept. 17	1,290	——	——	——	——	——	——	——	——	5,130
	Average		4,190		1,905	——	——	——	——	——	——	——	——	6,095
603	Full bloom	June 23	4,990	Aug. 18	3,260	——	——	——	——	——	——	——	——	8,250
613	Full bloom	June 23	4,890	Aug. 18	2,180	——	——	——	——	——	——	——	——	7,070
	Average		4,940		2,720	——	——	——	——	——	——	——	——	7,660
604	Flower bud	June 1	4,660	June 23	2,840	July 21	1,510	Sept. 17	987	——	——	——	——	9,997
612	Flower bud	June 1	3.220	June 23	2,370	July 21	1,340	Sept. 17	473	——	——	——	——	7,403
	Average		3,940		2,605		1,425		730	——	——	——	——	8,200
602	Succulent	May 2	1,581	June 1	1,470	June 23	2,870	July 13	750	Aug. 18	899	Sept. 17	900	8,470
606	Succulent	May 2	715	June 1	1,490	June 23	2,430	July 13	440	Aug. 18	551	Sept. 17	600	6,286
	Average		1,148		1,480		2,650		595		725		775	7,378

lines connecting the points of the curve do not necessarily represent the true reserve content of the roots on any given day other than the dates of sampling.

Fig. 1 shows that only the roots of the plants cut at the full-bloom and seed-pod stages maintain or increase their concentration of reserves between the last date of cutting and the beginning of winter dormancy.

The curves representing the roots of plants cut at the rosette stage show that when exhaustion, such as may be caused by cutting treatments, is carried to a point where the concentration of the carbohydrate reserves falls to 23 or 25% and the percentage of total nitrogen falls to about 1.5%, death of most of the plants occurs, and also a rapid decline in the recovery of growth of the plants surviving such severe cutting.

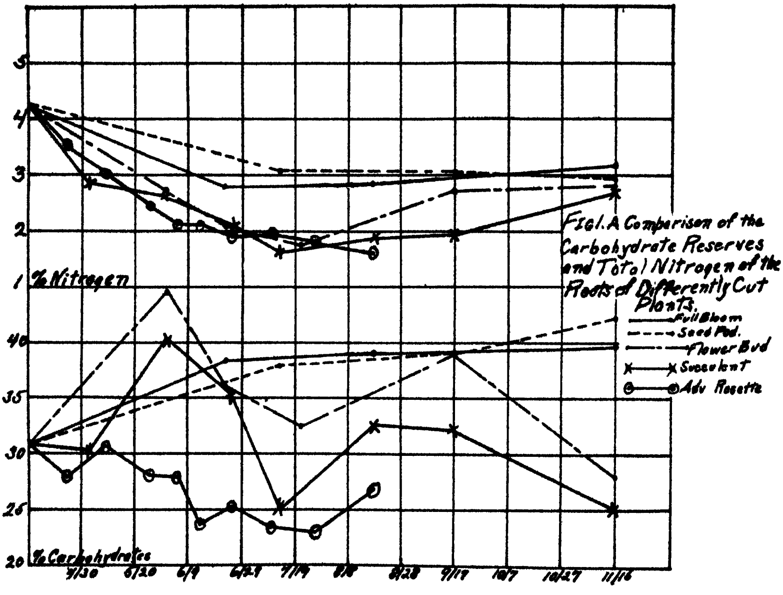

FIG 1.

From the large fluctuations of the carbohydrate reserves in the roots of the plants cut at the succulent and flower-bud stages, it would seem that these stages of growth are very near the point where replenishment or exhaustion of the root reserves by the top growth occurs. The estimation of the stage of growth reached by the plants at the time of cutting depends upon the judgment of the experimenter. Since an error of judgment of several days in time of cutting is easily possible, it seems quite probable that a difference of a few days in cutting may mean the replenishment or withdrawal of root reserves sufficient in amount to account for the fluctuations existing from time to time in the roots of the plants cut at these stages.

Fig. 2 is a comparison of the top growth of the differently cut plants in regard to total nitrogen and reserve carbohydrate content. It will be noted that the percentage of nitrogen is much higher in the top growth of plants cut frequently than in the roots where it is low. The stage of cutting, or the maturity of the top growth, does not appear to influence in any definite manner the reserve carbohydrate content which fluctuates in the majority of cases as shown in Fig. 2 between 18 and 23%.

If the weight in grams of 50 roots of the plants of the flower-bud series (Fig. 3) and the succulent series are followed through the

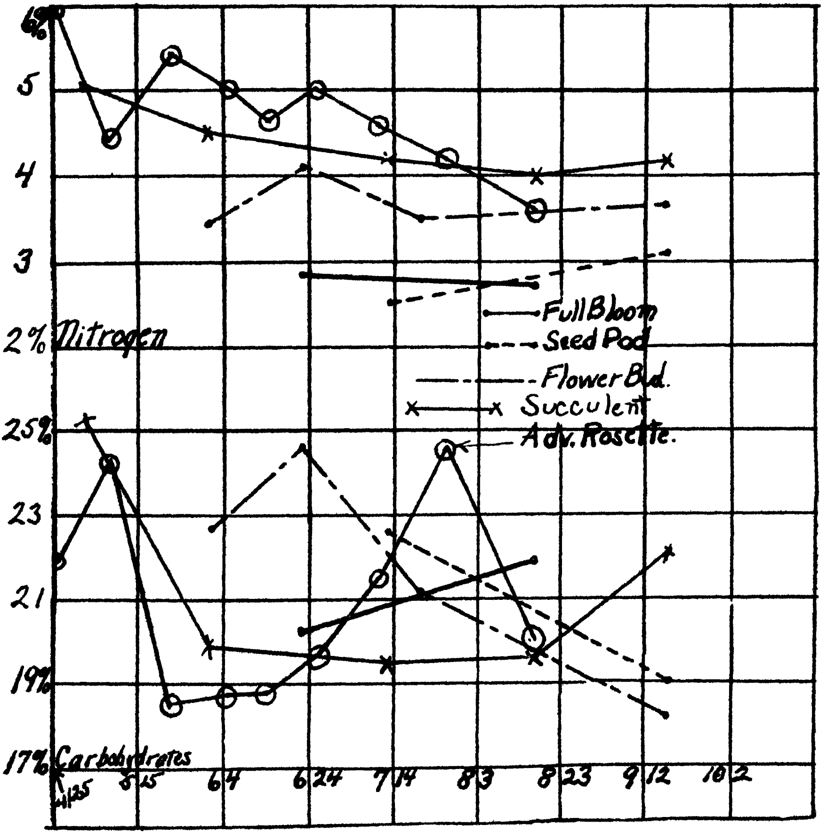

FIG. 2.—Comparison of the carbohydrate reserves and total nitrogen of the tops of differently cut alfalfa plants.

season for each cutting date, it will be seen that the dry weight of 50 roots remained low during the early part of the season and no appreciable increase in root size occurred except in the samples taken in the fall. The curves of Fig. 1 show a low concentration of reserves during the early part of the season. When the curves show an increase in reserves, as on Sept. 17, for example, the dry weight, and therefore the size of the roots, shows an increase. It would appear that root growth does not occur to any considerable extent when the concentration of reserve materials in the root is low, but when a higher percentage of food materials is present increase in size does occur.

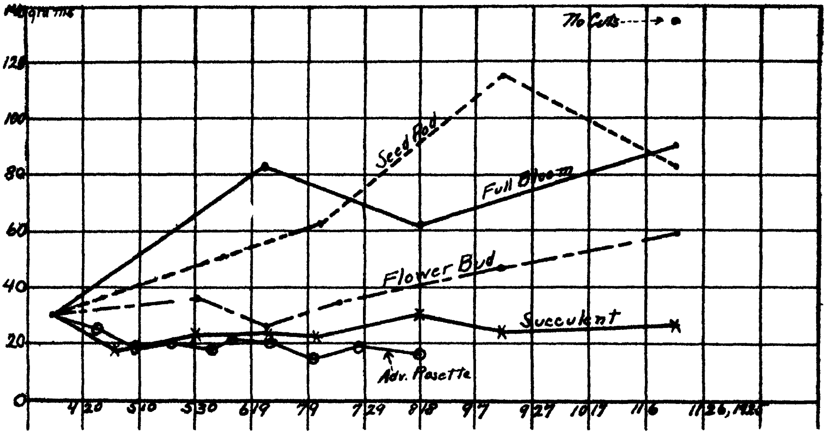

FIG. 3.—Comparison of the root weights of differently cut plants during the 1925 season.

A suggestion of what may happen in the case of the plants that received no cutting treatment and those cut at the full-bloom and seed-pod stages might be offered. The roots of plants which received these three cutting treatments did not show any considerable variation in percentages of carbohydrate reserves and total nitrogen. The dry weight in grams, however, of the 50 roots of plants that had not been cut at all was nearly 50% more than the roots of the seed-pod and full-bloom series dug on Nov. 16, 1925. It may be that storage of food reserves does not exceed a certain concentration. When this point is reached all food reserves, instead of accumulating still further, are used in increasing the development and size of the root. This suggestion is further strengthened by the fact that the percentage of reserve carbohydrates in the top growth remains fairly constant regardless of the stage of growth. As increase in the top growth is relatively small after the full-bloom stage and as photosynthesis is presumably still proceeding, surplus foods must be used by the plants either for seed production, for increase in cell wall thickness, for production of new top growth from the crowns or stems, for storage in the roots, or for increase in root development.

If the total amounts in grams of carbohydrate reserves and total nitrogen present in 50 roots of different series are compared, only samples taken at the same dates being used, rather large differences are found between the various types of cutting. Table 9 shows the wide differences in total amounts of nitrogen and reserve carbohydrates in the roots, the samples of alfalfa plants cut at the full-bloom stage being given the value of 100.

The average of all analyses of the samples of roots for each type of cutting treatments is shown in Table 10. The average percentage of dry matter for the roots of the plants cut at the rosette stage and representing one extreme of cutting treatment was 22.0, while the roots of the seed-pod series had an average dry matter content of 43.2%, an increase of nearly 100%.

TABLE 9.—*Comparison of the relative total amounts of the nitrogen and carbohydrate reserves present in the roots of 50 alfalfa plants on the dates indicated.*

Cutting treatment	June 23, 1925		August 18, 1925		November 16, 1925	
	Total nitrogen %	Carbohydrates %	Total nitrogen %	Carbohydrates %	Total nitrogen %	Carbohydrates %
Full bloom	100	100	100	100	100	100
Seed pod	——	——	——	——	85.7	99.3
Flower bud	22.6	29.1	——	——	57.0	46.6
Succulent	20.5	25.5	31.0	40.8	24.8	18.6
Rosette	16.2	15.7	15.1	19.0	——	——

TABLE 10.—*Average of all root samples as to percentages of dry matter, total nitrogen, total carbohydrates, and the weight in grams of 50 roots.*

Number of samples averaged	Cutting treatment	Average dry weight in grams	Average percentage of dry matter	Average percentage of total nitrogen	Average percentage of total carbohydrates
3	Seed pod	86.4	43.2	3.01	39.84
3	Full bloom	78.6	36.8	2.96	39.00
5	Flower bud	40.4	29.6	2.48	35.46
7	Succulent	24.1	25.0	2.22	31.52
9	Rosette	19.5	22.0	2.31	26.70

This difference between the roots of the differently cut plants is even more marked when the average dry weight of samples of 50 roots is considered. There was over 400% difference between the average dry weight (19.5 grams) of the roots of 50 plants cut at the rosette stage and that (86.4 grams) of the roots of plants cut in the seed-pod stage. All of the other averages of roots are progressive between these two extremes. The average dry weight of 50 roots of plants after cutting four times at the flower bud stage was 40.4 grams. The dry weight of 50 roots of this series in the early spring of 1925 was 30 grams. If one assumes these figures as being approximately representative of field conditions, it is apparent that there was only a small increase of root size in the plants cut four times at the flower-bud stage. Pronounced increases in root size occurred in plants cut at more mature stages. Due, perhaps, to a loss of carbohydrate reserves and nitrogen compounds by transference from the roots to the tops of plants cut at the rosette and succulent stages, actual decreases in dry weight of the roots of such plants occurred during the cutting season. The percentage of total nitrogen varied from 2.31 to 3.01 in roots of plants cut at the rosette and seed-pod stages, respectively.

Table 11 shows the relations of the average weight, percentage of dry matter, nitrogen, and reserve carbohydrates of the root samples of differently cut plants if the percentages present in the roots of plants cut at full bloom are given the value of 100. The average of the roots of plants cut at the seed-pod stages was in all cases slightly higher than the average of the roots of plants cut at full bloom. The roots of plants cut at the rosette, succulent, and flower-bud stages were all lower.

The averages of the samples of top growth of each type of cutting is presented in Table 12. It will be seen that the average dry weight and the average percentage of dry matter were always highest in the top growth of the plants cut at the more mature stages. The percentage of nitrogen was always highest in the growth cut at the immature stages in direct contrast to the corresponding roots (Table 10) where the percentage of nitrogen was relatively low at these stages. The percentage of reserve carbohydrates present in the top growth appeared to be relatively constant and not influenced by the cutting treatment applied.

If, however, the quantity of total nitrogen present in the tops is calculated on an acre basis for the differently cut plats, large differences, as shown in Table 13, are found. Using actual yield data (Table 8), it is found that the amount of nitrogen removed varies according to the cutting treatment given. The variation in the amount of reserve carbohydrates is never very large, except in the tops of plants cut at the seed-pod stage. This is probably due to the reduced yields of hay from the seed-pod plats. The differences in amounts of nitrogen harvested from the differently cut plants are surprisingly large. For instance, if the amount of nitrogen in the tops of the plants cut at full bloom is given the value of 100, the amount of nitrogen removed by the succulent growth rises to 150.3, equivalent to an increase of 91 pounds an acre. While the plats cut at full bloom removed 215 pounds of nitrogen from an acre, both the flower-bud and succulent plats removed over 300 pounds from an acre. If this situation is correlated with a soil low in nitrogen content, it opens the interesting problem of how far the application of nitrogenous fertilizers at the proper stage of growth can influence root exhaustion and lengthen the period of productivity of the top growth.

TABLE 11.—*A comparison of the relative weight and the percentage of dry matter and reserves of the roots of alfalfa plants receiving each cutting treatment.*

Cutting treatment	Total weight in grams	Percentage dry matter	Percentage total nitrogen	Percentage reserve carbohydrates
Seed pod	109.7	117.4	101.7	102.1
Full bloom	100	100	100	100
Flower bud	51.4	80.7	83.7	90.9
Succulent	30.5	67.9	75.0	80.8
Rosette	24.7	59.7	78.0	68.4

TABLE 12.—*Average of the dry weight, percentage dry matter, and reserves of the top growth produced by differently cut alfalfa plants.*

Number of samples averaged	Cutting treatment	Average dry weight in grams	Average percentage dry matter	Average percentage total nitrogen	Average percentage total carbohydrates
2	Seed pod	110.8	46.2	2.75	20.58
2	Full bloom	121.6	54.9	2.81	20.68
4	Flower bud	46.8	22.5	3.70	21.89
6	Succulent	29.5	18.8	4.43	20.21
9	Rosette	17.7	17.6	4.95	20.47

TABLE 13.—*A comparison of the total amounts per acre of total nitrogen and total carbohydrates in the top growth for each type of cutting.*

Cutting treatment	Yields in pounds per acre	Yields of total nitrogen in pounds per acre	Yield of total carbohydrates in pounds per acre	Total nitrogen and carbohydrates calculated to percentage basis	
				Nitrogen	Carbohydrates
Full bloom	7,660	215.7	1,594.4	100	100
Seed pod	6,095	163.6	1,277.0	75.8	80.1
Flower bud	8,200	306.5	1,616.9	142.1	101.4
Succulent	7,378	324.3	1,582.7	150.3	99.2

EXPERIMENT III

The purpose of this experiment was to discover the effect of various types of cutting upon two common pasture and lawn grasses, *viz.*, redtop and Kentucky bluegrass, with especial reference to root development, yields of dry matter, and encroachment of weeds.

On July 23, 1923, two strips of land that had been previously treated, as was the land sown to alfalfa in Experiment I, were sown, one to Kentucky bluegrass and one to redtop.

With favorable growing weather during the summer and fall of 1923, the redtop made a heavy matted growth 6 to 8 inches in length, and the bluegrass made a thick but shorter and more erect growth that was about 3 inches tall.

In the spring of 1924 the plats were measured and the first cutting was made May 17, 1924. The following cutting treatments were given to each plat for the balance of the year:

Plat 518 of the redtop and plat 521 of the bluegrass were cut when the top growth was fully mature. The method of harvesting was similar to that used in Experiment I.

Plat 516 of the redtop and plat 520 of the bluegrass were cut when the top growth was fully mature, as described for plats 518 and 521. In addition, all top growth was removed after fall growth had ceased at the beginning of winter dormancy.

Plat 517 of the redtop and plat 522 of the bluegrass were cut with a lawnmower at relatively infrequent intervals. The top growth was allowed to grow to a length of about 3 inches and was cut close to the ground to a length of about 0.5 inch. This type of cutting will be referred to as "close and infrequent" in the following discussion.

Plat 515 of the redtop and plat 524 of the bluegrass received a type of cutting designated as "long and infrequent," that is, the frequency of cutting was the same as for plats 517 and 522 but the cutting bar of the lawnmower was raised so as to allow about 1.5 inches of top growth to remain.

Plat 518 of the redtop and plat 523 of the bluegrass were cut close and frequently. The frequency of cutting of these plats was approximately twice that of the plats cut infrequently.

It should be stated that the lawnmower was equipped with a grass-catching attachment. The top growth obtained from the plats was air-dried and weighed to an accuracy of 0.5 ounce for each cutting. The yields thus obtained were then computed to an acre basis.

The yields of air-dry hay per acre during 1924 and 1925 under these different systems of cutting are presented in Table 14. The difference of 4,860 pounds in yield between plats 516 and 518 of the redtop was due to the rather large amount of aftermath that was removed from plat 516 on Oct. 28, 1924. The difference between similarly cut bluegrass plats 520 and 521 was only 2,840 pounds, but the yields of all plats of bluegrass were considerably less than for the redtop plats receiving the corresponding cutting treatments.

It will be noted that in 1925 the plats of both redtop and bluegrass that had the fall aftermath removed were considerably outyielded by the plats that retained their fall growth. The redtop plat 518 outyielded plat 516 by 420 pounds or 12%. The bluegrass plat 521 outyielded plat 520 by 804 pounds an acre or 37%. It would seem, therefore, that while both bluegrass and redtop are hardier than alfalfa they react in a somewhat similar manner in reference to fall cutting. Bluegrass appears to be more sensitive to this unfavorable treatment than redtop.

The redtop plat 518 cut once when mature yielded 6,980 pounds in 1924 and 3,480 pounds of air-dry hay per acre in 1925 in contrast to an average yield of only 4,795 pounds in 1924 and 2,404 pounds of air-dry hay in 1925 for all the cuttings which were made with a lawnmower on plats 515, 517, and 519. A similar but less marked difference occurred with the bluegrass cut at mature and immature stages (Table 14). Both redtop and bluegrass cut once while mature outyielded in a pronounced manner the yields from the frequent cuttings. These results are very similar to those obtained from alfalfa that had varied cutting treatments.

TABLE 14.—*Yields of dry matter per acre of redtop and Kentucky bluegrass.*

			1924		1925	
Grass	Plat No.	Cutting treatment	Number of cuts	Yields in pounds	Number of cuts	Yields in pounds
Red top	518	Mature	1	6,980	1	3,480
Red top	516	Mature and aftermath removed	2	11,840	2	3,060
Red top	515	Long and infrequent	13	5,050	6	2,425
Red top	517	Close and infrequent	13	5,412	6	2,938
Red top	519	Close and frequent	22	3,924	10	1,850
Bluegrass	521	Mature	1	5,960	1	2,172
Bluegrass	520	Mature and aftermath removed	2	8,800	2	1,368
Bluegrass	524	Long and infrequent	13	2,988	6	1,438
Bluegrass	522	Close and infrequent	13	3,312	7	2,088
Bluegrass	523	Close and frequent	22	3,336	9	1,863

In 1924 the redtop plat (519) cut closely and frequently yielded only about three-fourths as much dry matter an acre as did plat 517 cut less frequently. Between bluegrass plats 522 and 523 with similar cutting treatments there is no appreciable difference in yield for 1924 and only a relatively slight difference in favor of plat 522 during 1925.

In both 1924 and 1925 the plats of redtop and bluegrass cut long and infrequetly were considerably outyielded by those plats cut closely and infrequently, but a thicker turf was maintained with higher cutting. As measured by yields, close cutting in itself was not so detrimental in its effect upon the grasses as was the frequency of cutting.

Weeds were not very prevalent and were for the most part confined to the bluegrass plats that were cut with a lawnmower. The plats that were cut when mature contained practically no weeds. Plat 523 which was cut most frequently contained the largest amount of weeds, although plats 522 and 524 also had considerable numbers present.

On Nov. 29, 1924, and on Dec. 5, 1925, a block of soil 1 foot square and 7 inches thick, which contained the greater portion of the roots, was removed from plat 521 of the bluegrass that had been cut at the mature stage and from plat 523 of the bluegrass that had been cut most frequently. The soil was carefully washed from the roots, which were then preserved in alcohol and formalin for future detailed study. Because of lack of time this study has not as yet been made, but it can safely be said that the development of the underground parts of the bluegrass cut at a mature stage of growth exceeds by at least 50% the amount of roots and rhizomes present where the top growth is cut frequently at immature stages. It is evident that, as was true with alfalfa, the frequent cutting at immature stages retards subterranean development of bluegrass and redtop very markedly.

The effect of this retardation in the rhizome and root development from frequent cuttings was manifested by the rapidity of spring growth in the following year (1925). On April 25, 1925, the redtop and bluegrass having been cut but once when mature in 1924 had grown to a height of about 5 inches when the adjacent plat which was cut frequently in 1924 was less than half this height.

EXPERIMENT IV

In previous work by the author(1)an attempt was made to measure the reserve content of alfalfa plants that had received different cutting treatments in the field by transplanting large numbers of such plants into pots of sand and allowing the plants to grow in a dark room until no further growth was made. This top growth so obtained represented material that had been stored in the plants before transplanting into the dark room occurred. It was hoped in this way to obtain a measurement of the relative amounts of reserve foods present in plants grown under different conditions. As will be brought out in the following discussion and data, some interesting results were obtained. Roots of plants, both before and after exhaustive growth in the dark room, and also all cuttings of growth obtained from these roots were analyzed for total nitrogen and for reserve carbohydrates.

It is the purpose of this discussion to set forth the results of the chemical analyses of the roots and of the top growth of the plants used in this experiment. In order to understand the discussion, a short description of some of the more important phases and results of this dark room experiment will be given.

On Nov. 8, 1923, 100 three-year-old alfalfa plants that had been cut twice at the full bloom stage during 1922 and 1923 were dug and transplanted into pots of sand and placed in a dark room. Those plants will be called series A in this experiment. The plants were taken up after no more top growth was to be obtained from them, some of the roots were dried in an oven at about 80°, and subsequently analyzed.

Series B comprised 100 three-year-old alfalfa plants of the same seeding that had been subjected to three cuttings at the flower-bud stage in 1922 and 1923 which were also dug on Nov. 8, 1923, and treated as was series A.

Series C consisted of 100 three-year-old alfalfa plants that had only been cut twice at the full-bloom stage. They were treated as were series A and B.

Series D consisted of plants that were comparable to those of series C, except that they had been cut four times at the flower-bud stage. Of these 100 plants were taken and treated as described above.

Because of their smaller size, 200 seedling plants were selected and grown as described for series A. They will be referred to as Series E.

Records of the weight of each plant before and after dark room growth were kept. A record of the top growth produced by each plant in the dark room was also kept. A further trial was made in the spring of 1924 to determine whether the condition of fall dormancy of the alfalfa plants had an inhibiting effect upon the amount of dark room growth made by series C and D that were dug in the fall. On April 14, 1924, before field growth had started, 100 two-year-old plants that had been cut twice at the full-bloom stage were dug and transplanted into the dark room. These plants will be called series F. Another 100 plants, comparable in every respect except that they had had four cuttings annually at the flower-bud stage, were transplanted as those of series F. These plants will be called series H.

The results of these trials may briefly be summarized as follows:

1. Seedling plants of series E dug in the fall of 1923 produced a top growth amounting to 17.22% of the calculated dry weight of the plants. There was a total loss of 47.34% of the calculated dry weight of the roots in the dark room. After deducting the amount recovered as top growth the balance of the loss, 30.12%, was probably due to respiration, oxidation, and perhaps some leaching.

2. The three-year-old plants of series A had a total calculated loss of 25.03% of their dry matter in the dark room. Of this 25.03% loss, 14.25% was recovered in the form of top growth.

3. The frequently cut three-year-old plants of series B lost 30.5% of their calculated dry weight in the dark room. Only 9.88% was recovered as top growth. The roots of the plants cut frequently produced a much smaller percentage of top growth and had a greater loss of dry matter from respiration and oxidation than did those of series A which had been cut at the more mature stages.

4. The percentage of top growth produced by series C and D consisted of 16.21 and 15.86%, respectively, of the calucated dry weights of the roots. This difference is not significant. The amount of total dry weight lost by series D was 67.09%, and only 39.28% for series C. This again shows the tendency for the plants cut most frequently in the field to suffer the largest loss of dry matter by oxidation and respiration in producing a certain amount of top growth.

5. The top growths produced by series F and H represent 9.3 and 9.1%, respectively, of their calculated dry weights. Of these two series the largest loss of dry matter in the dark room occurred in series H where the loss was 19.8%, in contrast to the loss in series F which was only 11.4%, exclusive of the top growth produced.

6. While in all cases the amount of dark room growth was greatest from the plants that had been cut at mature stages in the field, in four out of the seven series the roots of plants that had been cut frequently gave practically the same amount of dark room top growth as did those plants that had been cut less frequently. The pronounced difference in total loss of dry weight of the roots was not so much caused by the amount of dark room top growth as by the loss from oxidation and respiration during the period of dark room growth. This loss in the plants cut early and frequently in the field was approximately twice that which occurred in the plants that were cut less frequently at more mature stages.

7. The average percentage of dry matter in the roots was from 4 to 10 less after dark room exhaustion than when the plants were taken from the field. This increase in percentage of moisture was greatest in the younger plants and in the plants that had been cut frequently in the field.

CHEMICAL DATA

As previously mentioned, all of the samples of series A, B, C, D, and E were oven-dried and samples consisted of 10 plants each. The samples of series F and H were preserved in alcohol as described in Experiment I. It is possible that some of the discrepancies existing in the data of series A, B, C, D, and E may be due to this method of drying, as well as to the rather small numbers of plants composing each sample.

The results of the analysis of samples of alfalfa roots dug in the fall of 1923 are presented in Table 15. The percentage of total sugars in series C and D is unusually low. The percentage of total carbohydrates in series B is slightly higher than in series A. No explanation other than that previously suggested can be offered for these unusual results.

Table 16 gives the results of the analyses of roots of plants after they had been grown in the dark room. The data show that the top growth does not remove all of the soluble carbohydrates from the roots, a concentration of 2½ to 5% being present even at exhaustion. It will be seen, however, as shown in Table 17, that the concentration of soluble carbohydrates in the top growth is considerably higher than that in the roots. There are no large variations in the composition of the top growth made by each series, but there is a tendency for the top growth produced by the young plants to be higher in total nitrogen than that produced by the older plants.

TABLE 15.—*Detailed analyses of roots of plants when taken from field Nov. 8, 1923.* All carbohydrate analyses expressed in terms of glucose.

	Series				
	A	B	C	D	E
Percentage moisture	36.5	36.4	32.7	31.2	No record
Percentage total nitrogen	2.33	2.17	2.82	3.03	3.74
Percentage reducing sugars	1.35	1.32	0.68	0.62	1.00
Percentage total sugars	11.74	14.00	2.65	3.13	7.52
Percentage dextrins and water soluble starches	2.46	3.52	3.19	4.05	2.06
Percentage starch	9.50	9.92	11.84	11.88	9.84
Percentage hemicellulose	10.50	9.50	10.86	9.66	11.80
Percentage total carbohydrates	34.20	36.94	28.54	28.72	21.22

TABLE 16.—*Detailed analyses of roots and plants after dark room exhaustion.* All carbohydrate analyses expressed in terms of glucose.

	Series				
	A	B	C	D	E
Percentage moisture	30.6	27.4	24.7	23.0	19.3
Percentage total nitrogen	2.05	1.90	2.41	2.88	3.30
Percentage reducing sugars	1.00	0.42	0.62	1.30	1.09
Percentage total sugars	1.55	1.26	1.43	1.30	1.09
Percentage dextrins and water soluble starches	3.41	1.12	1.21	1.40	2.05
Percentage starch	None	None	None	None	None
Percentage hemicelluslose	19.07	15.84	16.45	14.55	13.35
Percentage total carbohydrates	24.03	18.22	19.09	17.25	16.49

TABLE 17.—*Detailed analyses of top growth produced in the dark room (1923–1924).* All carbohydrate analyses expressed in terms of glucose.

	Series				
	A	B	C	D	E
Percentage total nitrogen	6.16	5.90	6.60	6.61	7.00
Percentage reducing sugars	2.00	1.51	1.49	1.27	1.05
Percentage total sugars	2.74	2.74	2.25	2.16	2.35
Percentage dextrins and water soluble starches	2.15	1.71	1.29	2.70	2.93
Percentage starch	None	None	None	None	None
Percentage hemicellulose	11.05	11.03	11.16	11.25	9.57
Percentage total carbohydrates	15.94	15.48	14.70	16.11	14.85

TABLE 18.—*Detailed analyses of plants subjected to dark room exhaustion in April, 1924.*

All carbohyrate analyses expressed in terms of glucose.

	Series F[a]	Series H[a]	Series F[a] (after dark room exhaustion)	Series H[a] (after dark room exhaustion)	Dark room top growth produced by	
					Series F	Series H
Percentage total nitrogen	3.58	3.74	3.31	3.42	7.46	7.63
Percentage reducing sugars	1.12	1.11	0.92	0.99	0.53	0.78
Percentage total sugars	7.37	5.25	2.99	2.83	2.34	2.57
Percentage dextrins and water soluble starches	1.07	0.49	0.44	0.78	1.43	1.39
Percentage starch	3.09	3.35	None	None	None	None
Percentage hemicellulose	15.68	15.20	16.65	16.51	8.89	7.76
Percentage total carbohydrates	27.21	24.29	20.08	20.12	12.66	12.72

[a] These samples were alcohol preserved and the methods described in Experiment I were used in obtaining these results.

Table 18 shows the composition of the plants of series F and H before and after being grown in the dark room, and the analysis of their top growth. It will be noted that the plants of series F were highest in carbohydrates at the beginning of the experiment, but the composition of series F and H was practically the same when taken from the dark room. The percentage of nitrogen in the top growth produced by the plants of series F and H was considerably higher than was the case of series C and D in Table 17, while the percentage of carbohydrates is lower.

Because of the limited nature of these dark room experiments, no very specific conclusions can be drawn. It is obvious, however, that important differences between plants subjected to different cultural conditions exist. This experiment, however, cannot be regarded as sufficient evidence that the amount of reserves contained in plants can be directly measured more accurately by means of dark room top growth produced than by ordinary chemical methods, although it should prove useful in supplementing the results so obtained.

APPLICATIONS TO AGRICULTURAL PRACTICE

The relations existing between various cutting treatments as to amounts of reserves in roots and the resulting responses of the plants have been brought out in the discussions of the experimental data. In making practical application of these findings various economic, soil, and varietal factors must be taken into consideration, thus preventing the formulation of specific rules applied to all conditions. The superiority of Grimm over common alfalfa in winter hardiness is demonstrated in these trials. Frequent and late fall cutting, which in the first year of cutting resulted in only slight winter injury with Grimm alfalfa, practically ruined the stand of common alfalfa. The results of these experiments indicate that Grimm alfalfa can tolerate unfavorable cutting practices to a much greater degree than common alfalfa. Its margin of safety with regard to cultural and climatic factors may be said to be greater than that of common alfalfa.

A point of importance to the plant breeder in northern climates is that unfavorable cultural practices, such as frequent cutting or the removal of fall growth of alfalfa, will soon eliminate from the field the weaker, less hardy, and hence most undesirable plants.

It has been demonstrated beyond any doubt that cutting of alfalfa at immature stages results in a lower content of reserves in the roots which inhibits their development. It seems very probable that there is a relationship existing between the susceptibility to winter-killing and the reserve content. It remains for the individual grower to decide whether he is willing to risk the longevity of his field by cutting more frequently at immature stages to obtain a hay slightly higher in percentage of proteins and of greater palatability or to cut at relatively mature stages that allow a high storage of reserves and vigorous root development combined with maximum yields. In any case except where the hay is to be used for special purposes, it is doubtful whether the increased quality of the hay cut at immature stages will pay for the difference in reduced yields and the additional labor of curing and harvesting more frequent cuttings.

The behavior of bluegrass and redtop in spite of occasional statements to the contrary follows the same trend as does alfalfa as far as yields are concerned. If the top growth of these grasses is cut frequently, such as would result from heavy grazing of meadows or the frequent cutting of lawns and golf courses, yields are considerably reduced, the turf becomes thin, and encroachment of weeds is encouraged. There are differences in degree of response between different grasses. It would appear that the removal of top growth in the fall has a weakening effect upon bluegrass and redtop similar to that found to be true with alfalfa. This is probably the result of some form of winter injury.

GENERAL DISCUSSION

The interpretation of each individual experiment has been discussed. It now remains to set forth a few general statements pertaining to all trials.

Some of the results obtained in Experiment II suggest some interesting possibilities of the relation of soil fertility and nitrogen fixation to the number of cuttings that can be given alfalfa without exhausting the available nitrogen supply of the soil. Cutting at the flower-bud stage removed over 300 pounds of this element per acre, whereas cutting at the seed-pod stage removed only slightly over one-half this amount. Obviously, unless nitrogen fixing and nitrifying organisms are more active when the plants are cut at the flower-bud and succulent stages the soil must soon become exhausted of all the available forms of this important and often limiting element. It may be possible that the pale green growth, so often observed after an immature cutting, is due to a scarcity of available nitrogen reserves in the roots. The question then arises as to the possibility of using nitrogenous and other fertilizers to hasten maturity and storage of reserves when alfalfa is cut more often than twice during the season. From the data of these experiments, it would seem that substantial increase in root size does not occur while the tops of the plants are still growing rapidly. As the top matures, its rate of growth lessens and some of the nitrogen compounds may be transferred back to the roots in addition to some of the products of photosynthesis. It may be that when the rate of growth lessens due to maturity or such limiting factors as drought or temporary soil deficiencies, the deposition of carbohydrates and nitrogen reserves and growth in the roots occur. It is possible that applications of nitrogenous and other fertilizers may so hasten the rate of top growth as to bring about earlier maturity and earlier storage of the carbohydrate and nitrogen reserves. Under such conditions three cuttings in short seasons, like those of Wisconsin, might be possible without very serious or immediate retardation of root growth and lessened yields. The increased amount of fall growth from two cuttings under these conditions in contrast to three cuttings, however, would have an important bearing on the winter injury which might ensue.

Another unexpected result of these trials was the large amount of winterkilling in the common alfalfa under all but the most favorable conditions. No studies of the composition of common plants comparable to the Grimm plants were made, but if the difference in composition is at all related to the large differences in resistance to winterkilling, interesting and valuable information would be obtained from such a study.

SUMMARY

1. Grimm alfalfa was much more resistant to winterkilling than was common alfalfa, especially on plats where the fall growth was removed and on the plats cut at immature stages.

2. The protection afforded to alfalfa plants by even small amounts of late fall top growth has a pronounced influence toward preventing winterkilling.

3. In the first year of cutting the largest yields of hay were obtained from plats cut at tenth-bloom and flower-bud stages. In the second year of cutting the largest yields of hay were obtained from plants cut at relatively mature or full-bloom stages.

4. Encroachments of weeds were greatest where the winterkilling was greatest, combined with cutting at immature stages.

5. It was found that cutting the top growth of plants at relatively immature stages retards root development to a marked degree.

6. Roots of plants cut at immature stages are invariably lower in percentage of dry matter than comparable roots of plants cut at more mature stages.

7. The percentage of total nitrogen and the percentage of reserve carbohydrates tends to be lower in roots of plants cut at immature stages, in contrast to the roots of plants cut at more mature stages of growth.

8. In the spring of the year, roots of alfalfa plants contain little starch and are relatively high in sugars.

9. During the summer, a considerable portion of the carbohydrate reserves in the roots of plants are in the form of starch.

10. At the beginning of winter dormancy roots of plants are relatively high in soluble carbohydrate reserves, while the percentage of starch is less than during the summer.

11. A high content of reserves in the roots and the initiation of new root growth do not seem to occur to any appreciable extent until the rate of growth of the tops is relatively slow.

12. The top growth of alfalfa plants cut at immature stages is

appreciably higher in percentage of nitrogen than is the top growth of plants cut at relatively mature stages. There is very little difference between the percentage of reserve carbohydrates in the top growth of plants cut at different stages.

13. Storage of starch does not occur to any appreciable extent in immature top growth of alfalfa. Such storage as was found was made only after the tops were relatively mature.

14. Under dark room conditions, plants will produce top growth that is considerably higher in percentage of nitrogen than top growth produced by plants in the field, as far as these experiments are concerned.

15. In a dark room, plants will produce top growth until the percentage of soluble carbohydrates in the roots becomes very low. In this experiment growth ceased when this concentration was from 3 to 5%.

16. The maximum yields of dry matter per acre from plats of Kentucky bluegrass and redtop were obtained from the plats cut at mature stages. It was found that the removal of the fall growth appreciably lessened the amount of top growth produced in the following season. Within the limits of the experiment, the behavior of the grasses with various cutting treatments was similar to that of alfalfa.

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SMUT STUDIES PRELIMINARY TO WHEAT BREEDING FOR RESISTANCE TO BUNT[1]

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Heavy losses occur annually in the wheat crop of the Rocky Mountain states due to stinking smut. This loss occurs both in reduced acre yields and in price. In 1925, 30% of the wheat crop in the vicinity of northern Utah and southern Idaho graded smutty. Much of this loss can be prevented by proper seed treatment, but that is expensive and in the past has not been too successful. In view of this fact, it seems evident that a more certain means of control is necessary. The most promising possibility appears to be through the development of resistant varieties.

EXPERIMENTAL

In the fall of 1925 the Utah Agricultural Experiment Station began extensive experiments with the view of attempting to solve the smut problem by the production of resistant strains.

The first problem was that of securing resistant stock which might be used in crosses. This problem was partly solved by the extensive smut resistant tests made by the U. S. Department of Agriculture cooperating with the California, Oregon, and Washington Agricultural Experiment Stations.[3] Out of this test came a few varieties highly resistant to stinking smut, none of which, however, are grown in Utah. Those proving most resistant were secured from the U. S. Department of Agriculture Office of Cereal Crops and Diseases and from the Washington Agricultural Experiment Station.

In addition, smut tests were made of a number of the leading varieties grown as winter wheat in this region, as well as a large number of both winter and spring strains of pure line and hybrid origin produced at the Utah Agricultural Experiment Station.

DRY-FARM TESTS

About 35 strains were used in the fall dry-farm tests. The experiment was planned to test the relative resistance of the various varieties and strains to stinking smut, *Tilleta tritici* (Bjerh.) Wint. and in addition to test or demonstrate the use of copper carbonate as a seed treatment for the control of bunt.

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[2] Assistant Agronomist. The writer wishes to express his appreciation to Dr. George Stewart, Agronomist, under whose direction these investigations were conducted.

[3] Tisdal, W. H., et al. Relative resistance of wheat to bunt in the Pacific Coast states. U. S. D. A. Bul. 1299. 1925.

Three rows from each strain were planted side by side. The first row had no treatment, the second row was heavily treated with powdered smut balls, and the third row was heavily treated with powdered smut balls after which it was treated with finely powdered copper carbonate. Two replications of each lot of seed were sown in the nursery in the usual way. The rows were about 12 feet long and a foot apart.

At harvest time the plants were pulled and counted. The data were based on the percentage of plants showing smut and not on the number of smutted heads. The former method is somewhat quicker, and from the standpoint of isolating highly resistant strains it is as effective. Strains do, however, vary greatly in this respect, as was very strikingly brought out in the variety Odessa with which there was a moderately high percentage of plants showing infection, though usually only one head on the plant and very often only a few kernels on a head showed infection. This naturally resulted in a

TABLE 1.—*Average percentages of smut-infected plants from two replications sown in fall of 1926, Logan, Utah.*

Strain	Number of strains tested	Average percentages of smut-infected plants		
		No treatment	Treated with powdered smut balls	Treated with powdered smut balls then with $CuCO_3$
Turkey	1	0.03	49.0	0
Kanred	1	1.1	30.5	2.1
Goldcoin	1	1.4	70.5	2.8
Silvercoin	1	2.1	82.8	2.5
J. W. Fife	1	1.1	89.5	0
Odessa	1	0	32.5	0
Imperial Amber	1		54.7	
Kofod	1	1.1	89.9	1.4
Kofod No. 388	1	1.4	93.9	0.5
Sevier Pure lines	5	2.5	85.0	1.7
Sevier x Dicklow	12	3.3	93.2	5.3
Sevier x New Zealand	1	0	92.9	0
Dicklow x Hard Federation	1	2.8	94.3	1.5
Dicklow x Hard Federation Federation x New Zealand	1	2.4	93.9	4.0
Hussar (C. J. 4843)	1	0	0	
Martin (C. J. 4463)	1	0	0	
Ridit (Wash. 2324)	1	0	0	
White Odessa (Wash. 2308)	1	0	0	
Hybrid 128 x White Odessa, F_5	1	0	0	
Average[a]		1.4	82.3	1.6

[a] Average based on those treated with smut and which showed some infection.

higher percentage of infection when the whole plant was taken as the basis than would have occurred had the head been the unit. Most of the other strains showed every head on the plant infected and the plants themselves much dwarfed. The data for the fall dry-farm tests are given in Table 1.

An examination of Table 1 brings out the fact that none of the common winter varieties grown in this section, nor any of the new hybrid or pureline strains, are resistant to bunt. Odessa was the only variety which showed any great degree of resistance, though the data in Table 1 do not indicate that it is any more resistant than Kanred. Odessa, however, is several times more resistant than Kanred, because, as previously stated, Odessa showed only a head or two on a plant and very often only a few kernels on a head that were infected. In addition, the infected plants of Odessa showed no signs of dwarfing, whereas with Kanred practically all the heads on infected plants were smutty and the smutted plants were much dwarfed. This dwarfing of infected plants was characteristic of all susceptible strains.

The varieties Hussar, Martin, Ridit, White Odessa, and Hybrid 128 X White Odessa, which were secured from the U. S. Department of Agriculture and from the Washington Station, proved to be highly resistant.

EFFECT OF COPPER CARBONATE

Table 1 also brings out the fact that copper carbonate, though not an absolute preventive of smut, has given very satisfactory results in its control. Seed so heavily treated with smut spores as to give an average of 82.3% infection when treated with copper carbonate showed a reduction to an average of 1.6%.

It is interesting to note that clean seed without any treatment gave an average of only 1.4% of the plants infected. This seed had been threshed in a small nursery thresher the previous year and some of the strains which had not been previously treated contained smut. It appears from this that unless seed contains smut spores when planted the chances for infection are rather slight in Utah.

SPRING WHEAT TESTS

In the spring smut test there were 224 strains tested. These included four local varieties, three pure lines of Sevier, one variety, and a hybrid strain secured from the Washington Station. All the other strains were of hybrid origin out of 11 different crosses made at the Utah Station. The seed was treated and sown in a manner similar to that for the fall dry-farm tests, except that there was only one row of each strain. The seed was sown early in the spring of 1926 when conditions were thought to be most favorable for infection to occur. Out of the 224 strains tested 8 showed no infection, 41 showed merely traces of infection, and all the others showed percentages of infection ranging from 4.3 to 54.3 based on the number of plants. The data for the spring tests are given in Table 2.

TABLE 2.—*Percentages of smut-infected plants from a single row of each strain sown in the spring of 1926, Logan, Utah.*

Strain	Number of strains tested	Range in percentage of plants smutted	Average percentage of smutty plants		
			No treatment	Treated with powdered smut balls	Treated with powdered smut balls then with $CuCO_3$
Hard Federation	1		0	23.4	0
Federation	1		0	8.4	0
Dicklow	2		0	21.2	0
Sevier	1		0	Trace	0
Sevier No. 59	1		0	Trace	0
Sevier No. 60	1		0	13.8	0
Sevier No. 101	1		0	Trace	0
Golden Ball (Wash. 1944)	1		0	0	0
Turkey x Marquis Wash. Wn. 326/576)	1		0	0	0
Federation x Sevier No. 60	9	4.3 to 22.0	0	11.2	0
Federation x Sevier No. 101	7	11.8 to 28.0			
Federation x Sevier	22	5.9 to 49.4	1	18.0	0
Dicklow x Federation	20	8.6 to 54.3	1	28.6	0.1
Dicklow x Sevier	19	6.0 to 34.0	0	13.5	0
Dicklow x Hard Federation	26	8.0 to 45.5	2	25.2	0.1
Dicklow x New Zealand x Hard Federation	17	9.3 to 47.6	0	24.1	0
Little Club x Dicklow	1		0	35.0	0
Commonwealth x Dicklow	4	17.0 to 47.0	0	29.2	0
New Zealand x Indian			0	31.0	0
Average[a]			0.03	21.3	0.01

[a] Based on those treated with smut spores which showed more than a trace of infection.

A study of Table 2 brings out the fact that most of the strains tested are susceptible to covered smut. As previously stated, only eight strains showed no infection. It is doubtful if any of these are resistant, as it is highly possible they escaped by chance. This is suggested by the fact that strains tested both in fall and in spring gave greater infection when fall sown. This is shown in Table 3.

TABLE 3.—*Percentages of smut-infected plants when strains treated with smut spoers were sown in fall and in spring.*

Strain	Percentage of infection Fall planted	Percentage of infection Spring planted
Sevier	79.8	Trace
Sevier No. 59	83.8	Trace
F 68	93.5	Trace
P 72	92.9	10.1
Q 193	94.3	26.9
RS 17	94.2	38.2

Those giving no infection when spring sown are being tested again to see if any are resistant. The two strains secured from the Washington Station, Golden Ball (Wash. 1944) and a strain out of a Turkey-Marquis cross (Wash. Wn. 326/576), were apparently as resistant in Utah as at the Washington Station.

EFFECT OF COPPER CARBONATE ON SPRING SOWN STRAINS

Table 2 also shows that copper carbonate is very effective in controlling covered smut on spring wheat. The average percentage of smutted plants for those showing more than a trace of smut when spring planted was 21.3. This same material when treated with copper carbonate showed an infection of 0.01%, almost perfect control. This substantiates the results of many other investigators that with ordinary seed wheat, which is not usually so well covered with spores, copper carbonate is a very effective treatment if properly done.

The data for the spring tests again bring out the fact that clean seed produces a clean crop as far as smut is concerned, that is, soil infection is not prevalent in Utah under present conditions.

There seems to be little likelihood that any of the good commercial varieties or any of the promising strains of hybrid origin show any high degree of resistance to smut. It appears, therefore, that the only hope is to combine the smut resistance of such varieties as Hussar, Martin, Ridit, etc., which are otherwise of no commercial importance in this section, with the desirable high-yielding characters of the well-adapted local varieties. Rather extensive investigations along this line are now well under way at the Utah Station.

SUMMARY

1. Preparatory to breeding for resistance, a rather extensive smut test was carried on with fall sown and with spring sown wheat in 1926 at the Utah Agricultural Experiment Station.

2. Some 260 strains of wheat were tested. These included local varieties, pure lines, and strains of hybrid origin developed at the Utah Station, and a number of resistant varieties secured from

the U. S. Department of Agriculture Office of Cereal Crops and Diseases and the Washington Agricultural Experiment Station, all of which gave no infection.

3. Of the local strains tested in the fall, none except Odessa showed any high degree of resistance. This was likewise true of the spring sown strains, except that eight of these showed no infection. This was probably due to chance and not to resistance, as spring planting produced much less infection than fall planting. The eight strains which showed no infection are being subjected to further tests.

4. With the resistant strains omitted the average percentage of infected plants was 82.3 for fall seeding and 21.3 for spring seeding. When similar but heavily smutted material was treated with copper carbonate the infection was reduced to 1.4 and 0.01%, respectively.

A COMPARISON OF SELECTIONS OF COAST BARLEY[1]

V. H. Florell[2]

Coast is the name applied to the strongly-bearded, 6-rowed type of barley which has been the leading variety of this cereal in California and adjoining states for decades. It is believed to have originated in North Africa near the Atlas Mountains (2)[3]. Its early history in California dates back to the settlement of the region by the Spaniards under the leadership of the padres as is shown by Hendry and Kelly (3) in their researches on the plant content of adobe bricks from the old missions. The period of reconstruction of the missions was from 1769 to 1824 in Upper California. The Spanish fathers must have brought this variety with them directly from Spain or from Mexico. It is interesting to note that Coast is the only type of barley so far found among the plant remains in the adobe bricks.

This variety of barley was found to be well adapted to the coastal region by the early settlers of the state. It is particularly well adapted to semi-arid climates and probably was the principal variety grown in Spain at the time of the colonization of North America.

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[1] Contribution from Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C., in cooperation with the California Agricultural Experiment Station from 1923 to 1926; previously in cooperation with the Office of Foreign Plant Introduction, Bureau of Plant Industry, U. S. Department of Agriculture. Received for publication April 16, 1927.

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[3] Reference by number is to "Literature Cited," p. 674.

Since the further settlement of the agricultural lands in California took place, Coast barley has spread to the great interior valleys where it was even better adapted than along the coast, and for many decades it has been the principal variety grown. It also spread to other western states where it is being widely grown.

Coast barley is a variety with mid-dense, 6-rowed spikes bearing stout scabrous awns from 15 to 20 cm long. Its kernels average large in size and are usually more or less bluish in color. In some markets it has been called "Blue Barley." It is moderately tall with a strong culm and resists lodging fairly well. The tenacious awns tend to persist after threshing so that bushel weights frequently are low.

California is one of the leading barley-producing states in the Union. At the beginning of the World War its annual production was approximately 40 million bushels, most of which consisted of Coast barley. At the present time several new varieties have replaced a considerable portion of the Coast acreage. The leading one of these new varieties is Club Mariout, of which the production last year amounted to almost one-half of the crop of the interior valleys. A considerable part of the crop of the state is used for feed purposes, but there is a large surplus which must be disposed of elsewhere. It usually is exported. The principal importing countries have been the United Kingdom and Scandinavia and other Northern European countries. In the United Kingdom, particularly, Coast barley has become well known as a brewing barley. The California product is well liked for this purpose on account of its consistently good condition from year to year. During the period of maturity and harvest there usually is no precipitation so that a bright clean crop nearly always is produced.

From the brewing standpoint the Coast barley is further desired on account of other characteristics. The nitrogen content is comparatively low. A protein content usually below 10.5% is reported by Le Clerc (4) in "Bay Brewing" which is a trade name formerly applied to a grade of Coast or "Common" barley. The kernels of export grades usually are moderately short and plump which is an advantage in malting. Furthermore, the consumer has become accustomed to the flavor of the ale produced so that there has been a brisk demand for this type of barley.

At the present time Coast is still the leading variety of barley in California. The grain produced, however, is not always of the best quality for brewing purposes. It is becoming more or less badly mixed with other varieties and in most sections of the state often contains a high percentage of so-called "shoepeg" barley. Considering this condition, it is quite evident that improvement of the Coast type of barley is desirable.

Close observation of a fully headed field of Coast barley will reveal that it consists of a collection of races or strains, but without very wide variation. The barley that was originally brought in must have contained a great many forms. It also may be that during the long period of cultivation here more or less mutation has occurred. The occurrence of natural hybrids also may have been a factor in causing new variation. Some plants are comparatively tall, others short; some are earlier than the average, others are later; some spikes are erect, others are nodding; some have widely spreading awns, in others the awns are appressed. Examination of the kernel also shows variation in pigmentation from a bluish tint to its almost entire absence. The plants with light colored kernels, however, are relatively very few.

In barley experiments conducted by the California Station at Davis and other points and by the Office of Cereal Crops and Diseases at Chico, no varieties of barley had been found up to about 1916 which were better adapted to California conditions than the Coast barley. Exporters had complained of blue barley and that the common barley produced was deteriorating. When the Cereal Office was doing its work at the Plant Introduction Station at Chico, it was decided to attempt the improvement of Coast barley by means of selection. The selections accordingly were made in the summer of 1917 by Dr. H. V. Harlan, in charge of Barley Investigations, and Mr. E. L. Adams, then in charge of the Federal Rice Station at Biggs, Calif. Some 365 head selections were made from commercial fields in the Sacramento and San Joaquin Valleys and at points on the coast north of San Francisco. These were threshed and the seeds sown by Mr. Adams in 5-foot head rows in the autumn of 1917.

EXPERIMENTAL METHODS

In 1918 the work was taken over by the writer. It was not possible to take agronomic notes on this planting because of late arrival at the station, but the rows were harvested and grain yields taken. The replicated single-row system of comparing the strains was used during the seasons of 1919–1921. From 1922 to the end of the experiment in 1926 the replicated triple-row system was employed with middle rows only harvested for yields of grain, except in 1922 when all three rows were harvested. A weighed or measured uniform amount of seed was sown each year in the comparative experiments. Beginning in 1921 and each subsequent year, Coast (C. I. No. 690) was grown as a check variety. In 1919 and 1920 the entire group of selections was grown in triplicate 20-foot rows. After harvesting the crop of 1920 the 2-year average yields of the barley selections were calculated and the lowest yielding selections eliminated. Selection of high-yielding strains was made by sections of the nursery rather than by consideration of the entire nursery on account of soil variation and the large number of strains. From one to three of the highest yielding ones were chosen from each nursery section containing 20 selections. In 1921 each of the 25 strains thus chosen was grown in five 20-foot rows with 19 of the remaining highest yielding ones in single rows for further observation. Due to excessive rainfall in the fall and winter of 1920–1921 spotted plant growth, with very low yields, was obtained. The yield data for that year are not comparable and therefore are not presented. In the fall of 1921 the work was transferred to Davis and the entire group of superior strains again were placed in replicated nursery rows. On account of lack of available fallow land for cereal work only three triple 20-foot rows of each of the Coast selections were sown for the 1922 crop. In the fall of 1922 the number sown was reduced to 16 of the highest yielding strains. Each of these was grown in five triple 20-foot rows until 1925, when all but five of the highest yielding strains were eliminated. The eliminated strains were retained in single 20-foot rows as a source of reserve material. Due to severe lodging and disease conditions that season, the strains in single rows were again put into the regular replicated series for final observations. In 1926 all of the Coast selections in the nursery were more or less badly lodged. Tabular data concerning methods employed in the nursery and plat experiment are given in Tables 1 and 2.

SELECTION OF A SUPERIOR STRAIN

In 1923 six of the highest-yielding selections from the nursery were placed in the plat experiment at Davis. After two seasons 276B was chosen as the best of the Coast selections. Since this time it has been continued in the plat experiment for comparison with standard commercial and other promising new varieties. The varietal name, Atlas, has been given to this strain.

Atlas was chosen as the best of the selections on account of its earliness, brightness, plumpness, color of kernel, and comparatively high resistance to lodging, as well as its high yield. With the exception of one year, 1925, it has been a consistently high yielder. It is about one week earlier than the Coast variety. It has comparatively stiff straw and shows greater resistance to lodging than

Table 1.—*Statistical data concerning methods employed in a comparative experiment in the nursery with selections of Coast barley at Chico and Davis, Calif., for the years 1917–1926.*

Year	System of replication	Length of row, feet	Number of replications Sown	Number of replications Harvested	Checks	Number of selections Sown	Number of selections In replicated rows	Number of selections In single rows	Number of selections Eliminated	Remarks
Chico										
1918	Head row	5	—	—	None	366	—	366	—	Five bundles lost.
1919	Single row	20	3	3	None	361	361	—	—	
1920	Single row	20	3	1	None	361	361	--	—	Two series of replications mowed for hay on account of un-uniformity of crop.
1921	Single row	20	5	5	Every 10th selection	44	25	19	317	19 selections grown in single rows for further observation. Low yields in all. Yield data not comparable.
Davis										
1922	Triple row	20	3	3	Every 10th selection	44	44	—	—	Replications reduced to three for lack of land. Selections put in regular varietal experiment. Side rows of triple row harvested for yields.
1923	Triple row	20	5	5	Coast sown in 10 triple rows	16	16	—	28	
1924	Triple row	20	5	5	Every 10th selection in 1st replication	16	16	—	—	
1925	Triple row	20	5	5	Every 10th selection in all replications	16	5	11	11	Eliminated strains retained in single rows for reserve. Yields low. Lodging and disease conditions bad.
1926	Triple row	20	5	5	Every 10th selection in all replications	16	16	—	—	Eliminated strains again replicated for recheck on disease and lodging. Lodging in all severe.

TABLE 2.—*Statistical data concerning methods employed in a comparative experiment in field plats with selections of Coast barley at Davis, Calif., for the years 1923–1926.*

Year	Plat unit in acres	Number of replications		Check variety	Number of selections		Remarks
		Sown	Harvested		Sown	Eliminated	
1923	1/50	5	4	Coast (690)	6	—	Selections in one replication near old gravel road discarded due to poor plant growth.
1924	1/50	5	4	Coast (690)	6	—	One replication on sand streak discarded.
1925	1/50	4	4	Coast (690)	2	4	Number selections reduced on account of shortage of land.
1926	1/50	5	5	Coast (690)	1	1	

does Coast. It has a plump kernel with a wrinkeld hull, both of which characters are desirable in brewing barley. The awns of Atlas are more readily removed at threshing than are those of Coast, resulting in higher bushel weight. Samples of this selection and of other promising varieties have been submitted, under disguising numbers, to the exporters of barley at San Francisco and all have expressed the opinion that Atlas is superior for export purposes.

COMPARATIVE YIELDS AND EARLINESS

Table 3 presents the nursery yields in bushels per acre of 16 of the best Coast selections in the six years, 1919–1926, first at Chico and later at Davis, with Coast (C. I. 690) as a check. Considering the average yield in bushels per acre at Davis, the range is from 58.2 to 71.4 bushels per acre. The three highest yielding of these were Selections 190B (C. I. No. 4606), 268B (C. I. 4119), and 170B (C. I. No.) with 71.4, 69.6, and 68.8 bushels per acre, respectively. Atlas (Selection 276B) yielded at the rate of 67.4 bushels and Coast (C. I. 690) at the rate of 64.4 bushels. The differences in yield of the four selections scarcely can be considered significant. In addition to a lack of plumpness of kernel the principal character in which each of the three highest yielding selections was considered inferior to Atlas was the distinctly blue color of 190B, the comparatively late maturity of 268B, and the tendency toward small "shoepeg" kernels in 170B. In applying Student's method for interpreting paired experiments, according to Love and Brunson (5) and Love (6), to the yields of 268B and 276B for the years 1919 to 1926, inclusive, the odds were only 16:1 that the difference in mean yield of 3.8 bushels was significant. This value is considerably below 30:1 which usually are the minimum odds considered significant.

Atlas was the earliest of all selections at Davis and was seven days earlier than Coast (C. I. 690), the check variety. The annual and average dates of first heading of the leading selections are given in Table 4.

Table 5 contains a comparison of yields of Atlas [Selection 276B (C. I. 4118)] and Coast (C. I. 690) for the four years, 1923–1926, when grown in replicated fiftieth-acre plats at Davis. The average yield of Atlas was 76.9 bushels and that of Coast (C. I. 690) 73.6 bushels per acre. This shows a slight increase of 4.5% in yield in favor of Atlas. By applying Student's method odds of only 2.81:1 in favor of Atlas are obtained. Atlas, however, has qualities which should make it more desirable for export purposes than common Coast.

TABLE 3.—*Annual acre yields of grain in bushels of 16 Coast selections and of Coast (C. I. 690) used as a check, when grown in 20-foot nursery rows at Chico, Calif., in 1919 and 1920, and at Davis, Calif., in 1922–1926, with average acre yields for a 6-year period omitting 1921, and the average at Davis.*

Selection No.	C. I. No.	Grams of grain in 5-foot head rows, 1918	Annual yields at Chico 1919[a]	Annual yields at Chico 1920[a]	Annual yields at Davis 1922[a]	Annual yields at Davis 1923[b]	Annual yields at Davis 1924[b]	Annual yields at Davis 1925[b]	Annual yields at Davis 1926[b]	Average yields Chico and Davis 6 years, 1925 omitted	Average yields Davis	Rank at Davis
Coast (ck.)	690	—	—	—	76.0[c]	83.0[d]	66.7[e]	44.0[f]	32.6[g]	—	64.6	10
40B	4605	134	35.9	45.3	93.1	92.3	47.3	—	41.4	59.2	68.5	4
45B	4603	—	30.5	52.5	94.3	90.3	44.2	—	42.5	59.1	67.8	5
84B	4121	77	31.9	58.8	93.1	82.9	57.1	45.4	36.0	60.0	67.3	7
100B	4120	330	40.3	56.3	88.2	83.4	65.6	42.1	28.2	60.3	66.4	8
170B	4117	134	37.3	78.4	80.9	96.7	64.6	41.3	32.0	65.0	68.8	3
171B	—	143	30.5	74.0	86.2	75.2	55.2	—	24.0	57.5	60.1	14
190B	4606	152	35.4	94.9	98.6	84.8	54.8	—	47.3	69.3	71.4	1
216B	—	161	24.0	86.8	91.4	65.6	48.4	—	27.5	57.3	58.2	15
217B	—	72	23.6	76.4	89.6	83.7	61.9	—	18.0	58.9	63.3	11
255B	—	82	31.2	86.3	91.3	78.9	47.3	—	37.8	62.1	63.8	10
268B	4119	170	37.8	97.6	97.3	88.8	61.7	44.1	30.6	69.0	69.6	2
276B	4118	135	28.4	93.5	91.3	84.0	68.4	33.9	25.7	65.2	67.4	6
302B	—	299	30.0	96.7	90.6	89.4	58.4	—	24.0	64.9	65.6	9
346B	—	248	29.5	102.2	93.2	67.8	43.8	—	27.8	60.7	58.2	15
361B	4604	268	42.9	79.1	97.1	69.1	54.5	—	30.7	62.2	62.9	12
365B	—	29	35.1	82.7	81.7	77.7	40.6	—	46.5	60.7	61.6	13

[a] Average of triplicate 20-foot rows (In 1920 only one series of rows was harvested on account of crop un-uniformity).

[b] Average of five 20-foot rows.

[c] Average of thirty 20-foot rows (side rows included).

[d] Average of ten 20-foot rows.

[e] Average of thirteen 20-foot rows.

[f] Average of twenty-four 20-foot rows.

[g] Average of twenty-five 20-foot rows.

TABLE 4.—*Annual and average dates of first heading of 16 Coast selections and of Coast (C. I. No. 690) in the eight years, 1919–1926, inclusive, at Chico or Davis, Calif.*

Selection No.	C. I. No.	Date of first heading in each year							Average date	
		At Chico		At Davis					In all years	In four years at Davis
		1919[a]	1920[b]	1922[c]	1923[b]	1924[b]	1925[b]	1926[b]		
Coast	690	April 17	April 17	April 24	April 7	April 11	April 7	April 9	April 13	April 12
40B	4605	April 19	April 25	April 25	April 7	April 16	April 14	April 18	April 18	April 16
45B	4603	April 15	April 13	——[d]	April 2	April 10	March 28	April 1	April 6	Aplr 3
84B	4121	April 16	April 15	April 22	April 6	April 12	April 6	April 8	April 12	April 11
100B	4120	April 16	April 11	April 21	April 5	April 10	March 29	April 3	April 10	April 8
170B	4117	April 16	April 10	April 21	April 4	April 12	March 29	April 3	April 10	April 8
171B	——	April 16	April 15	April 22	April 5	April 13	April 8	April 10	April 13	April 12
190B	4606	April 15	April 10	April 21	April 6	April 12	April 4	April 3	April 10	April 9
216B	——	April 16	April 10	April 22	April 6	April 12	April 8	April 5	April 11	April 7
217B	——	April 14	April 9	April 21	April 1	April 11	April 7	April 5	April 10	April 9
255B	——	April 17	April 12	April 23	March 28	April 13	April 6	April 5	April 10	April 9
268B	4119	April 16	April 11	April 24	April 10	April 13	April 5	April 6	April 12	April 12
276B	4118	April 12	April 5	April 17	April 2	April 10	March 25	March 31	April 6	April 5
302B	——	April 17	April 10	April 22	April 6	April 12	April 3	April 3	April 10	April 9
346B	——	April 17	April 10	April 21	April 5	April 12	April 4	April 3	April 10	April 9
361B	4604	April 13	April 8	April 16	April 4	April 12	April 1	April 3	April 8	April 7
365B	——	April 19	April 17	April 24	April 12	April 18	April 10	April 13	April 16	April 15

[a] Average date of first heading on three replications.

[b] Date of first heading on single row.

[c] Average date of first heading on two replications.

[d] No note on date of first heading.

TABLE 5.—*Annual and average acre yields of grain in bushels of Atlas (276B) in comparison with Coast grown in replicated fiftieth-acre plats at Davis, Calif., in the four years 1923–1926, inclusive.*

Variety	C. I. No.	Annual acre yields in bushels				4-year average,
		1923[a]	1924[a]	1925[a]	1926[b]	yield, 1923–1926
Atlas (Sel. 276B)....	4118	112.5	67.1	49.2	78.8	76.9
Coast.............	690	103.2	59.8	70.3	60.9	73.6

[a]Average of four plats.
[b]Average of five plats.

COMPARATIVE PLUMPNESS

Plumpness of kernel in barley is important because it indicates a normal development of grain and also a large reservoir of starch located within easy reach of the diastatic enzymes of the scutellum (7). Table 6 contains data on the dimensions, kernel weight, degree of plumpness, and bushel weight of 15 of the best Coast selections compared with Coast (C. I. 690) and Club Mariout (C. I. 261) in the year 1924. Club Mariout at present is the leading competitor of Coast barley. Data on three varieties and Atlas (Sel. No. 276-B) in the year 1926 also are included for comparison.

The index of plumpness was the ratio of width to length of kernel. Kernel widths were obtained by measuring the total distance in centimeters occupied by 50 kernels laid side by side, either dorsally or ventrally, on coordinate paper. The kernels were placed on a straight line with the widest point of each on the line. Similarly, to determine lengths the kernels were laid end to end in a straight line on coordinate paper, the total length recorded, and the average determined. The tip of the palea was considered the distal end of the kernel. The plumpness of barley ordinarily is estimated by the width of the kernel in its middle portion. "Shoepeg" barley usually has the sides nearly parallel from the base of the kernel to its tip. Plump kernels, on the other hand, are broader and well rounded near the middle.

As a numerical expression of plumpness it is believed that the width, which is the greatest variable, divided by length will serve reasonably well. This ratio varies from 0.275 to 0.315 in the selections studied. The highest ratio (0.315) is that of Selection 346B and the next highest (0.308) is that of Atlas (Sel. 276B). This indicates that Atlas is superior in plumpness to all others but one of those studied. The plumpness of the original Coast (C. I. 690) in 1924 was 0.283 and that of Club Mariout 0.275. In 1926 the highest degree of plumpness among the four varieties (0.331) was possessed by Atlas, while that of Coast was 0.306.

TABLE 6.—*Dimensions, kernel weight, plumpness ratio, and bushel weight of 15 Coast selections and the two leading commercial varieties from the nursery experiment at Davis in 1924, and of four varieties, including Atlas (Sel. 276B), from the plat experiment in 1926.*

C. I. No.	Selections and varieties	Dimensions and weight per kernel (mean of 50 kernels)			Plumpness of kernel expressed in ratio of width to length	Test weight per bushel in pounds
		Width, mm	Length, mm	Weight, mg		
			1924 Crop			
4605	40B	3.20	10.89	45.5	0.291	41.0
4603	45B	3.26	11.34	40.2	0.287	43.0
4121	84B	3.06	10.24	36.7	0.298	39.5
4120	100B	3.06	10.66	35.7	0.287	38.0
——	171B	3.16	10.80	40.2	0.290	42.5
4606	190B	3.18	10.70	39.3	0.294	38.0
——	216B	3.04	10.60	34.2	0.287	38.0
——	217B	3.16	10.40	40.3	0.304	41.5
——	255B	3.20	10.82	38.8	0.296	41.0
4119	268B	3.20	10.66	38.3	0.300	40.0
4118	276B (Atlas)	3.20	10.40	38.7	0.308	45.5
——	302B	3.10	11.28	40.5	0.275	41.0
——	346B	3.24	10.28	42.1	0.315	44.0
4604	361B	3.08	10.72	37.6	0.287	39.0
——	365B	3.20	10.64	39.8	0.300	41.0
690	Coast	3.00	10.60	33.4	0.283	37.0
261	Club Mariout	3.18	11.56	44.7	0.275	42.0
			1926 Crop			
4118	Atlas (276B)	3.54	10.70	49.1	0.331	46.0
261	Club Mariout	3.46	11.12	53.8	0.311	47.0
1367	Vaughn	3.38	10.58	45.8	0.320	46.5
690	Coast	3.20	10.46	40.2	0.306	41.5

Inspection of the test weights shows that there is a fairly close correlation between plumpness weight per bushel.

OTHER DIFFERENCES

A study was made of the morphology of the spikes from the 1926 crop of the different Coast selections in an effort to find some character distinguishing Atlas from the Coast variety. There was striking similarity in nearly all characters of the spike in all selections. The color of the dehulled kernel was the only character of the mature spike showing definite variation. The dehulled kernel of Selection 170B (C. I. 4117) has remained consistently without pigment. That of Atlas is light in color but with occasional traces of the bluish color. The kernel of 190B (C. I. 4606) is definitely bluish. Except in extreme cases, such as Selections 170B (C. I. 4117) and

190B (C. I. 4606), the color of dehulled kernel cannot be of much use in identification on account of the variation in pigmentation in different seasons and on account of the similarity of this character in different strains.

In some strains it was observed that at the time when the kernel had begun to fill the flowering glumes were striped with red along the nerves. This coloration is due to anthocyan pigment in the nerves (1) and might be of some use in identification, but a comparative study of this character was not made.

Notwithstanding the similarity of the characters of the spike, there are others showing definite variation as, for instance, the comparative height of plant and resistance to lodging (Fig. 1). Other characters showing quite wide differences were earliness and yield (Tables 3 and 4). Differences in such characters demonstrate definitely the occurrence of strains or races in commercial Coast barley.

The Coast selections showed some differences in susceptibility to Rhyncosporium or "leaf scald." Estimated on a scale of 0, 1, 2, 3, 4, and 5 as degrees of infection (with plus or minus variations), the Rhyncosporium infection of the selections listed in Table 1 ranged from 1— to 3+ in 1920, from 3 to 4+ in 1921, and from 0 to 2 in 1924. The degrees of infection of Atlas (selection 276B) in the years 1920, 1921, and 1924 were 3+, 4+, and 1, respectively. The rank of Atlas in yield during these years was 5 in 1920 (93.5

FIG. 1.—A view of some of the Coast selections in the nursery at Chico, Calif., in 1920, showing variation in height, earliness, and lodging.

bushels as compared with 102.2 bushels for the highest yielding strain), 1 in 1921 (32.2 bushels against 31.8 bushels for the next highest), and 1 in 1924 (68.4 bushels against 66.7 bushels from Coast, the next highest).

In the absence of other distinguishing morphological characters than the plumpness of Atlas (Selection 276B), it will be necessary to make use of the early maturity and the color of its dehulled kernel for identification.

DISCUSSION

While this paper is intended primarily to present data and the results of an experiment in selection in barley, it emphasizes the importance of certain factors in a selection experiment with cereals.

Uniform soil is fundamental for good experimental work, but it is highly important for the first two or three years of a selection experiment. This is the time when the entire number of individuals is compared for elimination of the majority of the inferior strains. With variable soil some of the best individuals may be eliminated and thus lost. To forestall such possibilities where soil variation is known to exist the entire group of selections may be grown for a greater number of seasons. Ordinarily, with the initial stage continued for at least three seasons, the experimenter has sufficient data to enable him to choose most of the best strains with reasonable certainty. However, both lack of time and funds usually are deciding factors in the duration of this stage of the experiment.

After the best individuals have been chosen continuity of experiment is important in order to get an average reaction to the various environmental factors to which they are likely to be subjected. If an individual is promising enough to be included in a comparative experiment it should be retained for a sufficient number of seasons so that a definite idea of its reaction in yield and other characters may be obtained. It may then be discarded without a doubt lurking in the mind as to some desirable quality having been overlooked. In the opinion of the writer, under conditions similar to those obtaining in the Sacramento Valley, selected strains or varieties should be continued in frequently replicated rows for from three to five seasons and in plats for at least five seasons. During the progress of an experiment occasional varieties occur in which characters are uncovered which clearly show them unfit for further trial.

That a check variety serves as a useful standard of comparison is recognized now generally. In the initial stage of this experiment no check variety was included. It was decided that the highest yielding individuals could be chosen without the use of a check variety. In general this is true, but a check variety probably would have served as an additional guide in the selection of superior strains. Frequent checks beginning with the head rows are desirable. The seed of head rows and checks should be spaced uniformly for best results. With the triple-row nursery system a check variety every tenth selection serves fairly well, although a check every fifth selection should be more useful where abrupt soil variations may occur. Checks in all replications are desirable.

SUMMARY

Coast barley was the earliest type of this cereal grown in California and was first introduced during the period of Spanish settlement. Its cultivation spread over the entire state and over the far western mountain region where it has been the principal variety for decades.

Before the World War almost all of the annual barley crop in California consisted of Coast barley. It now shares honors with Club Mariout and other varieties.

As an export barley it has received considerable favor in barley-importing countries for brewing purposes.

Important characteristics of Coast as an export barley are the usually dry, bright character of the crop, its comparatively low nitrogen and high starch content, and plumpness of kernel.

Coast barley as grown commercially consists of a number of strains, or races, which however do not show great variation.

Improvement of Coast barley by selection from commercial fields was begun at Chico in 1917, when somewhat over 350 head selections were made.

The head selections were grown in 5-foot head rows in 1918 in triplicate, single 20-foot nursery rows in 1919 and 1920, and in replicated triple 20-foot rows from 1922 to 1926.

The data for the first three years (1918 to 1920) were obtained at the Plant Introduction Station, Chico, Calif., and for the last five years at University Farm, Davis, Calif.

The entire group of selections was grown in triplicate for the two years 1919 and 1920 for a comparison of yield and agronomic characters. In the fall of 1920, 44 of the highest yielding and best strains were chosen for further trial and observation.

Grain yields in 1921 were very low and unreliable as a result of excessive winter rains and are not presented.

The cereal experiments were transferred to Davis in the fall of 1921. The Coast selections were grown in three triple rows in 1922 and in five triple rows each for the years 1923 to 1926 with Coast (C. I. 690) as a check variety.

In 1923, the number of the superior strains in the nursery was reduced to 16, and 6 of the best of these were included in the plat experiment where they were continued for two years. From nursery and plat yields and agronomic data, 276B was selected as the best strain. It has been continued each year for further trial in the regular plat experiment. This strain has been named Atlas.

In the plat experiment Atlas has given slightly better results than Coast (C. I. No. 690). Considering its yield, earliness, plumpness of kernel, and resistance to lodging, it is an improvement on this common California barley. Further improvement of this type of barley doubtless can be effected by further selection.

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SOME VALUES OF THE STATISTICAL METHOD IN PLAT WORK[1]

(Abstract)

J. P. JONES[2]

This paper deals with the four questions:

1. How large shall the plats be?
2. What shall be the shape of the plats?
3. What is the minimum number of plats that can be allowed for each treatment?
4. How shall the plats be arranged?

The data used in discussing these questions were chiefly those obtained in tobacco experiments. It was pointed out that in plat work the statistical method can be used to advantage, but that caution should be exercised in interpretation. Considering the variations in plant characters, it was shown that from 4 to 19 plants were needed to measure a 10% difference in tobacco. Where sorting is done, as is the case with Havana seed tobacco, and records must be made on the small segregates, the size of plat should not be reduced below 1/40 acre even though variation in plant characters might suggest a smaller size.

It was shown that the amount of replication necessary for tobacco depends on the size of the difference to be measured and the variability of the soil. The number of plats required to measure a 10% difference in the 1924 and 1925 tobacco crops at the Massachusetts Agricultural Experiment Station varied from three to six.

The shape of plats was discussed chiefly in the light of the work of Lyon, Mercer, and Hall. From the standpoint of probable error and mechanical manipulation, the long, narrow plat was considered preferable.

The problem of arrangement of plats was left somewhat unsettled. The Latin Square method of Fisher and the pairing method of Student were mentioned. The latter has been used at the Massachusetts Agricultural Experiment Station for tobacco and for the differences to be measured it has been satisfactry.

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[1] Abstract of a paper read at the meeting of the New England Section of the Society held in Boston, Mass., Dec. 3, 1926. Received for publication April 15, 1927.

[2] Assistant Research Professor of Agronomy, Massachusetts Agricultural College, Amherst, Mass.

STATISTICAL PROBLEMS IN NEW ENGLAND PLANT BREEDING[1]

(Abstract)

P. C. MANGELSDORF[2]

The plant breeder usually deals with relatively small differences. In New England the soil variation is so high that differences of over 200% are found in the same variety grown in different parts of the same field. As a result the probable error is often abnormally large. Increasing the number of replications, which theoretically reduces the probable error, may actually increase it by introducing additional soil heterogeneity.

Adjusting to check rows corrects for soil variation to some extent but may be very unfair to individual varieties. Pairing the observations and calculating the odds by Student's formula seems to offer the best method of establishing small differences between varieties when the soil variation is high. Obviously it is impossible to compare every variety directly with every other variety by the pairing system. It is possible, however, to compare each variety with a common check variety and this is the system now being tested at the Connecticut Station. By the use of this indirect method it has been possible to establish the significance of small differences which do not appear to be significant when the probable error is calculated by Bessel's or Peter's formula.

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[1] Abstract of a paper read at the meeting of the New England Section of the Society held in Boston, Mass., Dec. 3, 1926. Received for publication April 15, 1927.

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A LONG VERSUS A SHORT ROTATION FOR THE NEW ENGLAND DAIRY[1]

(Abstract)

J. P. HELYAR[2]

The present system of land management on New England dairy farms was developed in response to specific conditions of climate, soil type, labor supply, and competitive factors which are probably less evident today than the practices they established. In any attempt at readjustment so that greater net income may be realized, the question arises as to changes in the rotation system and the relative values of the long and short rotation in effecting the improvement of soil fertility which is fundamentally important to the more efficient production of forage crops.

If there be at present a typical rotation on such farms, it is the so-called long rotation which, generally speaking, is well suited to the soil type, topography, and labor supply of many of these farms. It has failed, not because of its length, but because regular additions of plant food to maintain production have not been included in the scheme. It would seem from experience and experiments that the long rotation with necessary adjustments as to plant food supply, including lime, will best meet the needs of many of these farms.

The New England dairy farm differs from the short rotation farm of the middle western states in that the acreage in hay is so much greater than the total of other crops in the rotation. To shorten the rotation and to include the entire present acreage of crops on the farm in such a system would involve a labor need that makes the attempt prohibitive. For some farms a combination of the two systems may be the most desirable. The production on areas which are costly as to tillage can be maintained with soil amendments. That portion of the acreage which permits of easy tillage may be carried in short rotations. With lime and mineral fertilizers and more frequent crops of clover it would seem that distinct gains could be made relative to the proportion of legume hay available.

DISCUSSION

B. C. HELMICK, in discussing this paper, remarked that in deciding upon a change we should consider whether the economic situation has changed and stated that this depended largely upon whether we can grow grain as cheaply as we can buy it.

"Is forage the only thing to be considered?" he asked.

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[1] Abstract of a paper read at the meeting of the New England Section of the Society held in Boston, Mass., Dec. 4, 1926. Received for publication April 15, 1927.

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WHAT IS NOT BUT SHOULD BE KNOWN ABOUT EXTENDING THE LENGTH OF THE DAIRY ROTATION BY USING FERTILIZERS[1]

(Abstract)

J. S. OWENS[2]

The dairy rotation must be chiefly or exclusively to raise hay, corn, and pasture. The problem is, how successfully can the meadow be kept a meadow, the pasture a pasture, and the corn lot kept in corn by the aid of commercial fertilizers from the three standpoints of quantity of production, quality of crops, and economy?

Data from Missouri, Delaware, New York, Connecticut, Rothamsted, and Massachusetts on top dressing hay indicate that hay yields can be kept at a rather high level for many years, but that weeds creep in and the yields finally decrease somewhat and very rapidly if no top dressing is applied.

Clover and alfalfa are benefited by mineral top dressings.

Evidence was presented to the effect that corn could be grown continuously with rather high yields, but here, as in the case of hay, the high cost of the fertilizer in maintaining the yield is a big factor.

Experimental data from Connecticut were cited to prove that pastures are also helped by top dressing. Cheaper fertilizers offer much hope in this respect.

Permanent meadows of grass hay do not supply the quality of forage needed. It may be wiser to shorten the rotation, grow more legumes, and improve the quality of the hay.

"Our problem, then," it was concluded, "is not how long our rotations can be made, but whether or not they can supply the quality of hay needed and whether or not long rotations will produce the feed crops needed at the lowest cost."

DISCUSSION

J. B. ABBOT, in commenting upon this paper, said, "It is difficult to say just what the New England rotation is, but I would like to believe that it consists of corn, a cash crop, seeding down to oats, clover, and hay for three or four years. This, however, is not followed in the majority of cases and too often the rotation is a hit and miss one, leaving the hay down until the yield is no longer profitable.

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[1] Abstract of a paper read at the meeting of the New England Section of the Society held in Boston, Mass., Dec. 4, 1926. Received for publication April 15, 1927.

[2] Extension Agronomist, Connecticut Agricultural College, Storrs, Conn.

"Growing legumes means shortening the rotation and more frequent plowing. Keeping a field to hay for any length of time means using fertilizer to keep up the yield. The aim in our dairy farming should be to extend the rotation as long as yields can be maintained at a profitable level.

"Grass hay is not as efficient as clover, but measured by the economic yardstick it is the only kind of hay the New England farmer has grown at a profit, for at the cost of production, timothy hay appears to be better than the legume hay which so many people advise."

PASTURES AND DAIRYING[1]

(Abstract)

M. GALE EASTMAN[2]

So long as New England's tillage area or improved land is constantly decreasing, pasturing may hold its own in acreage or available forage in spite of the aggressiveness of bushes, the durability of rocks, and the decrease in total land acreage of farms. If we add to this the fact that grazing livestock is tending to decrease in quantity also, the acutness of a possible pasturage shortage, or problem of maintenance even, may be considerably alleviated indefinitely.

Pasturage is cheap feed, and considering the area involved, there is little stimulus to do much pasture improvement so long as any kind of pasture is available. Should pasture become so scarce that barn feeding must be substituted, the cost will be five or six times as much and the farmer will then become interested in pasture improvement and will be able to show figures to substantiate any unwonted enthusiasm which he may develop. The vital questions for investigators to answer are three:

1. Do we approach such a situation on farms either individually or collectively, occasionally or continually?
2. How far do we have to go in this direction, or how near must we approach the ultimate condition before some improvement may be undertaken economically?
3. When something has to be done, what is most feasible?

These questions are easy to ask but hard to answer. Our knowledge of pasture production and maintenance is meagre.

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[1] Abstract of a paper read at the meeting of the New England Section of the Society held in Boston, Mass., Dec. 4, 1926. Received for publication April 15, 1927.

[2] Associate Agronomist, New Hampshire Agricultural Experiment Station Durham, N. H.

With suggestions that information should be gathered and compiled along this line in connection particularly with the introduction of sweet clover, some figures were reviewed showing the trend in quantities of stock pastured in New England and the number of acres required to pasture an animal unit. Grazing stock has decreased about 3% per year for the last few years and about 7 acres of pasture are used per animal unit at the present time.

Some comparisons were made with assumed figures relating to the costs and returns to be expected between maintaining large acreages of present pasture or establishing smaller tracts of sweet clover as a substitute. It was assumed that the sweet clover would give some six weeks more value in actual pasture, due to its ability to withstand drouth and to grow early in spring and late in fall; that annual maintenance of fences would cost 5 cents a rod; that average pasture land was worth $16.00 per acre and fields for sweet clover $64.00; and that an acre of sweet clover properly handled would pasture an animal unit per season.

The figures used indicated that the annual cost of maintaining sweet clover established on reasonably good tillage land would be some $15.00, while the cost of rent, fencing, and extra barn feeding on present average pasture in comparison is likely to cost $17.00 per animal unit per season.

Such criteria as the increased quality of feed indicated and the decreased loss of energy apparent in searching for it were suggested but not evaluated. In the hypothesis no provision for maintenance of present pastures was allowed for except fencing costs.

Finally, averages do not mean much. The individual is on one side or the other. Some farmers can doubtless be found whose conditions are so far from the average that such measures can be adopted without question. Then we shall accumulate some facts that may be applied more specifically to individual cases.

DISCUSSION

E. J. MONTAGUE, as critic, stated that pastures are now deteriorating, and suggested three ways out of the dilemma, *viz.*, first, fertilize the best area; second, bring pastures into the rotation; and third, utilize sweet clover.

"At the Massachusetts Station," he reported, "A night pasture has been utilized by a rotation of corn, hay, and three years in pasture."

EVALUATING CROP ROTATION AND THE USE OF FERTILIZERS[1]

(Abstract)

W. W. WEIR[2]

The total benefits of crop rotation may be compared with the benefits derived from the use of fertilizers, measured in terms of the increases in yields which may be effected by these farm practices. Results of long-continued fertility experiments are desirable. Comparable data must concern a particular crop grown in continuous culture, fertilized and unfertilized, and grown in rotation, fertilized and unfertilized. In as much as the long-time experiments were not planned with a view to evaluating the benefits of rotation, the analysis and interpretation of the available data are attended with problems.

One problem concerns the selection of results obtained from fertilized plats. Should single-plat yields be selected, or should the yields of several fertilized plats in a series be averaged and treated as a single or composite yield? When one considers, for example, the 18-year average yields obtained in the 3-year rotation test at Wooster, he will observe that there is but little difference between the yields obtained wth mixed fertilizers. If the results obtained on the various plats show statistical significance they should not be averaged. But how may any significance be determined? Here the probable-error formulas can not be used. The Student method has been recommended for interpreting fertilizer tests.

The Student method is a means for obtaining a mathematical expression of statistical significance or nonsignificance, based on the parallelism of small-sample results. However, this is no magic formula for converting any paired results into profound and useful scientific knowledge. In interpreting fertilizer results plain common sense in most cases may prove of greater value than the Student method, as it is commonly applied. If one member of a pair of yields is always greater, no matter how little the difference, the odds in favor of it will be more than 10,000 to 1. Again, one yield may show high odds over another, while the actual increases resulting from the two treatments may be exactly the same so that there can not possibly be any significance in favor of the higher yield.

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[1] Abstract of a paper read at the meeting of the New England Section of the Society held at Boston, Mass., Dec. 4, 1926. Received for publication April 15, 1927.

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A critical study of the Student method will lead one to believe that in analyzing fertilizer data the interpretation of results should be based on the parallelism of *gains* rather than of yields. When the Student method is applied to gains or increases in yield, results will show that it would be best to select single-plat fertilizer results in evaluating the benefits of fertilizer in rotation and in continuous culture.

Another problem attending the interpretation of fertility data in evaluating the benefits of rotation and the use of fertilizer concerns the different values that may be obtained for these two farm practices. These different values may be well illustrated by the 8-year comparable average yields of corn obtained on the Morrow plats at Urbana, Illinois, furnished by Dr. F. C. Bauer, as follows: c, 26.7 bushels; cf, 36.4 bushels; cr, 49.9 bushels; and cfr, 66.6 bushels. Let c represent the yield obtained in continuous culture and also the number of bushels to be credited to cultivation alone, without fertilizer and rotation; cf is the average yield obtained with fertilizer alone, including the bushels credited to cultivation; cr, the average yield in rotation without fertilizer, including bushels credited to cultivation; and cfr, the yield when the use of fertilizer and the practice of crop rotation are combined, including the bushels credited to cultivation.

Ordinarily, rotation and the use of fertilizer are evaluated as follows: cfr (66.6)—c (26.7) = fr (39.9). cfr (66.6)—cr (49.9) = f (16.7). fr (39.9)—f (16.7) = r (23.2).

If the formula, fr—f = r, is correct, then cfr (66.6)—cf (36.4) = r (30.2) is also correct. But in the first case the value for rotation is 23.2 bushels, and in the second case it is 30.2 bushels. The assumption is that we can determine the absolute values for rotation and the use of fertilizer in fr (39.9 bushels).

We must recognize two values for rotation and for the use of fertilizer, as follows: cr (49.9)—c (26.7) = r (23.2), and cfr (66.6)—cf (36.4) = r (30.2). cf (36.4)—c (26.7) = f (9.7), and cfr (66.6)—cr (49.9) = f (16.7).

The relationship of these values may be illustrated as follows:

Number of bushels credited to cultivation alone, or the average yield when corn is grown in continuous culture (c)	26.7
Increase effected by fertilizer (f)	9.7
Additional increase effected by rotation (r)	30.2
Total yield when practices are combined	66.6 bushels

Again, number of bushels credited to cultivation alone, or the average yield when corn is grown in continuous culture (c)	26.7
Increase effected by rotation alone (r)	23.2
Additional increase effected by fertilizer (f)	16.7
Total yield when practices are combined	66.6 bushels

It is to be noted that the absolute values for rotation and the use of fertilizer in fr (39.9) can not be determined, and that there is an unallocated value equivalent to 7 bushels contained in 39.9 bushels.

These problems are more fully discussed by the author in the *Journal of Agricultural Research*, 31: 949–956, and in U. S. D. A. Bul. 1377.

DISCUSSION

HENRY DORSEY, in an exhaustive criticism of this paper, cited data from Rothamsted, Ohio, Illinois, Missouri, and Minnesota. Except for purposes of scientific evaluation, he thinks that the two factors of rotation and fertilization should not be separated. The ultimate outcome of rotation cropping is a more complete exhaustion of the elements of soil fertility. The aim, therefore, should be, in his opinion, to combine a good rotation with as rational a system of fertilization as economic conditions will permit.

SHOULD THE NEW ENGLAND FARMER MAINTAIN TWO CROPPING SYSTEMS, ONE WITH LIME, THE OTHER WITHOUT?[1]

(Abstract)

M. F. MORGAN[2]

Soil acidity surveys in Connecticut show that reaction conditions on soils of southern New England are about as follows: General crop land, 4.6 to 5.6 pH, with an average near 5 pH; tobacco land, average from 5.2 to 5.4 pH. Indications as to lime requirement of these soils give figures which show that most soils of the region under discussion need from 2 to 6 tons of limestone to bring the reaction near the neutral point, and the probable average is about 3 tons $CaCO_3$.

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[1] Abstract of a paper read at the meeting of the New England Section of the Society held in Boston, Mass., Dec. 4, 1926. Received for publication April 15, 1927.

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The work of the Rhode Island Station, as well as the contributions of Arrhenius and others, has brought about the belief that corn, potatoes, oats, rye, red top, and probably timothy, as well as many other crops, can be grown satisfactorily on soils with reactions as low as 5 pH, provided that adequate fertility is maintained.

Should the farmer plan to lime his entire crop acreage to the point where the most acid-sensitive crops will thrive, or should his farm be so planned that certain portions of it are kept at a favorable reaction for such crops as alfalfa, beets, and onions, while the rest of the tillable land is seeded only to the more acid-tolerant crops?

An alfalfa campaign in Connecticut has greatly increased the amount of lime used in that state. Perhaps this is largely due to the belief of the farmer that a crop has been found which will amply pay for the cost of lime on the one field of the farm for which he has the money to buy lime. On the other hand, there are surely some farmers who hope to get the entire tillable area of the farm in a proper condition to grow alfalfa, so as to realize the full economics of manure and fertilizers to be gained through the introduction of a pure legume into the cropping system.

In some cases it is particularly important to keep the soil at a considerable degree of acidity. Areas to be cropped to tobacco and potatoes rarely receive lime, due to dangers from disease troubles on soils which have been heavily limed. The tobacco or potato farmer, if he is also to grow acid-sensitive crops, must of necessity maintain two conditions of soil reaction on his farm.

Fields in truck and market garden crops are frequently planted to vegetables which are much injured by acid-soil conditions. Though certain other crops may not need lime, it is probable that the best practice is to keep such fields at a reaction of 6 pH or above. This cannot be accomplished without lime.

It is believed that we can logically expect lime to be used in quantity for those portions of our cropped area which are to be set aside for alfalfa, truck, or market garden crops. Lime in smaller amounts may be used for general field crops and tobacco. The day when all cropped areas of New England are brought to a condition of neutral or very slightly acid reaction through the use of several million tons of lime and when the relatively cheaper ammoniates which many agricultural writers predict may enable us practically to dispense with acid-sensitive legumes in a section where the return from commercial fertilizers should become increasingly great is too far in the future to be pictured.

DISCUSSION

B. G. Southwick, in a letter which was read at the close of the presentation of the above paper said, "We already have a crop system here in New England without lime. Whether it maintains production and is satisfactory can be judged in numerous ways. The big problem is to work out cropping systems that will not be prohibitive in the amount of lime needed and yet which will be more satisfactory and profitable than the altogether too common system of a cultivated crop from one to three years and then hay almost indefinitely."

AGRONOMIC AFFAIRS

MINUTES OF MEETING OF THE NEW ENGLAND SECTION

The New England Section of the American Society of Agronomy met at the Boston City Club, Boston, Massachusetts, December 3 and 4, 1926, for the 13th annual meeting. About 30 agronomists and others interested in Agronomy attended the various sessions. The following program was presented.

DECEMBER 3, 7 P. M.

Banquet, followed by smoker. Dr. A. B. Beaumont, presiding.

After dinner topic: "The Service of Statistical Methods in Agriculture." Papers were presented as follows:

"The Place of Statistical Methods in Agronomy," by J. R. Jones.
(Abstract printed elsewhere in this issue.)

"Statistical Problems in New England Plant Breeding," by P. C. Mangelsdorf.
(Abstract printed elsewhere in this issue.)

Discussion led by Director W. L. Slate, Jr.

A report of the committee on freight rates for lime was read by J. S. Owens. An increase of from 25 to 80% in freight rates on agricultural liming materials since 1913 was noted, the increase in freight being greater than the increase in cost of the limestone itself.

According to the committee, the cost of shipping agricultural limestone in Minnesota is 1 cent per ton per mile with a minimum rate of 60c, while in Connecticut the lowest freight rate is $1.80.

Further studies are suggested in order to get information on the following:

1. Existing commodity rates in New England with mileage and class rate and a computation of the class rate to the commodity rate.
2. Similar information from the Central Freight Association and Trunk line territories must be had for comparison.
3. Rates in all three territories established by exception to classification on lower than classification basis must be assembled.

More complete information is needed to justify a case before the Interstate Commerce Commission and to persuade railroad officials that a reduction in freight rates will mean larger business. Larger loadings might increase car-mile earnings and decrease the tonnage rate. Comparative freight rate data were presented.

The committee was continued.

The committee for the revision of the New England standard nine fertilizers had no report to make, but the committee was continued.

After a discussion of tariff on fertilizer, the following motion was passed, "That this group go on record as believing that all fertilizer and materials imported for and suitable for use as fertilizer be placed on the free list."

The secretary was instructed to formulate a statement of the position of the group in this matter to be sent to the Senators and Representatives of New England.

DECEMBER 4, 9:00 A. M.

SYMPOSIUM ON "CROP SUCCESSION"

1. "A Long vs. a Short Rotation for the New England Dairy Farm." Analyst: J. P. Helyar. Critic, B. C. Helmick.

(Abstract printed elsewhere in this issue.)

2. "What is not but Should be Known about Extending the Length of the Dairy Farm Rotation by using Fertilizers." Analyst: J. S. Owens, Critic, J. B. Abbot.

(Abstract printed elsewhere in this issue.)

3. "Has the Temporary Pasture a Place in the Dairy Business?" Analyst: M. Gale Eastman. Critic, E. J. Montague.

(Abstract printed elsewhere in this issue.)

4. "How Some Crops affect succeeding Crops." Analyst: B. L. Hartwell. Critic, S. B. Haskell.

(See THIS JOURNAL, 19:255–259. 1927.)

5. "The Rotation vs. Fertilizers in Maintaining Yields." Analyst: W. W. Weir. Critic, Henry Dorsey.

(Abstract printed elsewhere in this issue.)

6. "Should the New England Dairy Farmer maintain two Rotations, one with Lime, the other Without?" Analyst: M. F. Morgan. Critic, B. G. Southwick.

(Abstract printed elsewhere in this issue.)

The original papers are on file with the Secretary of the New England Section and access to them may be had by addressing him.

At the business meeting, the officers for the past year were reelected. These are, A. B. Beaumont, Massachusetts Agricultural College, President; Ford S. Prince. University of New Hampshire, Secretary.—FORD S. PRINCE, *Secretary.*

NEWS ITEMS

H. W. ALBERTS, who went to Alaska last fall to become Senior Agronomist at Sitka, was appointed Director of the Alaska Experiment Stations on April 1. C. C. Georgeson, who has been in charge of the U. S. Department of Agriculture investigations in Alaska since 1898 and Director of the Alaska Stations since 1924, will continue there as Senior Agronomist to complete his investigational work.

KANSAS STATE AGRICULTURAL COLLEGE conferred the honorary degree of Doctor of Science upon Professor Andrew Boss, head of the Department of Agronomy and Farm Management of the University of Minnesota, at the recent Commencement.

R. W. THATCHER, Director of the New York State and Cornell University Agricultural Experiment Stations and Editor of this JOURNAL for the past six years, has been elected President of Massachusetts Agricultural College at Amherst and will assume his new duties on September 1, 1927.

H. M. TYSDAL, formerly assistant in the agronomy department at the Kansas State Agricultural College and who has been Assistant and Instructor in agronomy at Minnesota while studying for the Ph.D. degree, has been appointed to a fellowship on the American-Scandinavian Foundation, New York, for nine months study under Nilsson-Ehle and Akerman of the Plant Breeding Station at Svalöf, Sweden.

W. C. COFFEY, Dean of the Department of Agriculture of the University of Minnesota and Director of the Minnesota Agricultural Experiment Station, was the recipient of the honorary degree of Doctor of Laws granted by Hamline University, June 7, 1927.

JAMES F. MARTIN has been appointed agent of the Office of Cereal Crops and Diseases of the Bureau of Plant Industry, U. S. Department of Agriculture, to have charge of the cooperative cereal experiments at the Moro, Ore., Substation, effective June 10, 1927.

M. A. MCALL has completed his graduate work for the doctor's degree at the University of Wisconsin and resumed his duties as Agronomist in charge of cereal agronomy investigations for the Office of Cereal Crops and Diseases of the U. S. Department of Agriculture on June 11, 1927.

JOHN R. WOODWARD has been appointed Field Assistant, effective June 6, to assist in the experiments in the production and improvement of cereals conducted at the Arlington Experiment Farm by the Office of Cereal Crops and Diseases of the U. S. Department of Agriculture.

HOWARD B. SPRAGUE, Assistant Professor of Agronomy and Assistant Agronomist at the Minnesota college and station, respectively, has been appointed head of the Division of Soils and Crops in the New Jersey college and station, effective July 1, 1927. This Division includes the extensive work in plant breeding and in soil microbiology.

B. A. MADSON, who has been Associate Agronomist of the California college and station, with headquarters at the University Farm, Davis, has been appointed head of the Division of Agronomy. R. L. Adams, who has been acting head of the Division, will continue his work in agricultural economics.

E. W. LINDSTROM, head of the Department of Genetics of the Iowa college and station, will be on leave of absence for the coming college year. He will go to Paris as representative of the International Education Board to assist the Directors, especially with their fellowships in biology and agriculture.

Dean E. J. IDDINGS of the College of Agriculture, University of Idaho, is on a six-months leave of absence and is making a tour around the world to study agriculture, particularly animal husbandry.

W. L. BURLESON, head of the Department of Agronomy of the Illinois College of Agriculture and president of this Society, was given the honorary degree of Doctor of Agriculture by the Oklahoma Agricultural and Mechanical College on May 31.

R.A. OAKLEY, Senior Agronomist in Charge of Forage Crops, Bureau of Plant Industry, United States Department of Agriculture, who has been in ill health for more than a year and who has spent the past several months in California, is reported to be recovering rapidly. His condition is said to be better than at any time since he left the East, and his many friends will rejoice at the prospect of speedy and complete recovery.

C. R. BALL, Senior Agronomist in Charge of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, has been appointed chairman of the recently created Department Corn Borer Committee. This committee is composed of eleven members representing nine different bureaus. Its purpose is to assemble all Departmental information on the corn borer now available for extension forces, to outline a program of corn borer research in agronomy, agricultural engineering, agricultural economics, animal industry, dairying, chemistry, botany, climatology, and any other fields which may appear important to promote this program, and to correlate it with those of states and other agencies.

THE RECENT movement of the combined harvester-thresher into the sub-humid and then into the humid grain-producing sections of the United States has raised many new and important questions for the experiment stations and the federal Department of Agriculture. As a result a comprehensive program of cooperative investigation was carried on in 1926 in the Great Plains area by federal and state forces. The offices engaged in the cooperative study were the Office of Cereal Crops and Diseases of the Bureau of Plant Industry, the Division of Farm Management and Costs and the Grain Division of the Bureau of Agricultural Economics, and the Division of Agricultural Engineering of the Bureau of Public Roads, and the departments of Agronomy, Agricultural Economics, and Agricultural Engineering of several state agricultural experiment stations. In 1926 the study was conducted in Texas, Oklahoma, Kansas, Nebraska, and Montana. During the harvest season of 1927 a similar cooperative study is under way in Virginia, Pennsylvania, Indiana, Illinois, and North Dakota.

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SYMPOSIUM ON "PROCEDURE AND RESULTS OF SMALL GRAIN BREEDING"

Leader: T. A. Kiesselbach, University of Nebraska, Lincoln, Nebr.

1. "Theoretical Aspects of Small Grain Breeding." C. E. Leighty, U. S. Department of Agriculture, Washington, D. C.
2. "A Program for Selecting and Testing Small Grain in Successive Generations following Hybridization." H. H. Love, Cornell University, Ithaca, N. Y.
3. "Mechanical Operations of Small Grain Breeding." C. F. Noll, Pennsylvania State College, State College, Pa.
4. "What has been Accomplished by Breeding Small Grains?" R. J. Garber, University of West Virginia, Morgantown, W.Va.
5. "Distribution and Maintenance of Improved Varieties of Small Grains in Canada." L. H. Newman, Central Experimental Farms, Ottawa, Canada.

1. THEORETICAL ASPECTS OF SMALL GRAIN BREEDING[1]

C. E. LEIGHTY[2]

The theoretical aspects of small grain breeding might easily occupy the entire time allotted to this symposium. Consideration will be limited, however, to some of the more important features of inheritance and related phenomena in the small grains. It will not be possible to present very much of the supporting evidence. and much of that presented will be drawn from experiments with wheat, the crop with which the writer is most familiar.

There is no separate science of genetics for the small grains. The principles and theories of this science are found to apply in wheat, oats, barley, and rye plants as they do in other species. But in breeding these crops special problems are presented in the solution of which intimate knowledge of the plants and their reactions is required. The mode of reproduction, the relationships of different forms, the facts of variation, the effectiveness of selection, the possibilities of recombination, the limiting factors—these and other questions present themselves to the breeder.

MODE OF POLLINATION

With the exception of rye, the small grains are all naturally self-pollinated. In all of them, however, a small amount of crossing may occur. This varies to some degree with the variety but appears to be largely dependent on environmental conditions. Reviews of literature have been made by Pope (20)[3] and by Hayes and Garber (17).

Natural crosses in wheat have been reported by many observers. At least 2 or 3% for several years was reported at the Minnesota Station. At Arlington Experiment Farm, near Washington, D. C., natural hybrids between wheat varieties and between wheat and rye are found each year. Usually the percentage of such crossed plants is rather small, but in certain varieties as many as 10 to 15% or more have been observed at times. Such crossing may occur in any variety it seems, but it appears to be more common in varieties being grown somewhat out of their most favorable environment. For instance, Kanred wheat is so badly cross-pollinated at Arlington Farm that attempts to keep it pure by roguing have been abandoned. High percentages of crossing often appear to be due to pollen abortion or to rudimentary anther development. It has been found to be about six times as frequent in wheat spikes produced by the less vigorous secondary tillers than in the more vigorous primary ones.

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[1] Paper read as a part of the symposium on "Procedure and Results of Small Grain Breeding" at the meeting of the Society held in Philadelphia, Pa., December 31, 1926.

[2] Agronomist in Charge of Eastern Wheat Investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry, Washington, D. C.

[3] Reference by number is to "Literature Cited," p. 703.

In partially sterile species hybrids natural crossing may be more frequent than in ordinary wheat. Hayes, Parker, and Kurtzweil (18) found that about 18.5% of the F_3 plants in certain families of crosses between *Triticum vulgare* and *T. durum* were natural hybrids, evidently due to crossing in the F_2. No data on natural crossing in the parental varieties were recorded and presumably very little or none was noted. Crossing in partially sterile hybrids is facilitated by the behavior of unfertilized flowers, which may remain open for several days.

Oats are known to cross naturally, as has been shown by several observers. Stanton and Coffman (31) report 0.97% of crossing at Akron, Colo., in Iowar and from 0.10 to 0.33% in three other varieties. Griffee and Hayes (13) report the number of aberrant types, resulting from natural crossing, as ranging from 0.04% in Victory to 1.4% in Kanota. The actual amount of natural crossing would be at least twice as great as is indicated by these figures. Apparently cross fertilization occurs somewhat less frequently in oats than in wheat.

Barley is more likely to be self-pollinated than wheat, as it frequently blooms before the spike emerges from the sheath. Natural crosses in barley have been reported by several observers, however. Harlan estimates that the Nakano Wase variety has shown 5% of hybrid types in certain years at Arlington Farm.

Rye is practically self-sterile. As a rule only an occasional seed is produced by isolated plants. Occassionally, however, a plant is found that is highly self-fertile and from such plants it is possible to establish self-fertile lines. Rye plants from selfed seed are much less vigorous than normal plants and selfed lines are difficult to maintain, even those that exhibit a high degree of self-fertility.

The frequent occurrence of natural crossing in the small grains demonstrates the necessity of care in the handling of material to be used for inheritance studies. Unless effective methods are employed to protect parent plants the ancestry of the progeny can not be known with certainty. Even a slight degree of crossing, especially in the F_1, may lead to very erroneous conclusions. Again it is quite essential that the purity of the parents of a cross should be known. The use of an F_1 natural hybrid, for instance, instead of a homozygous individual, as conceivably is possible, might result in very unusual ratios in later generations. Perhaps undetected natural crossing at times has been responsible for reported mutation and complicated and unusual Mendelian ratios.

GROUPING OF THE SMALL GRAINS

It has been found that species of oats and wheat occur in groups differing in chromosome number and in several other respects. On the other hand, no similar groups of barley and rye occur. All the known forms of cultivated barley have seven haploid chromosomes. Likewise all forms of rye have seven chromosomes, although occasional plants with eight chromosomes have been found (2).

The groups of *Avena* have been established (22) as follows: *A. strigosa* with 7 haploid chromosomes, *A. barbata* with 14, and *A. algeriensis*, *A. byzantina*, *A. sterilis*, *A. fatua*, and *A. sativa* with 21.

Three groups of *Triticum* have been established on botanical, physiological, and cytological grounds as follows:

Group I	Group II	Group III
T. monococcum	*T. durum* Desf.	*T. vulgare* Vill.
	T. turgidum L.	*T. compactum*
	T. polonicum L.	*T. sphaerococcum* Perc.
	T. dicoccum Schubl.	*T. spelta* L.
	T. pyramidale Perc.	
	T. orientale Perc.	
	T. persicum Vav.	
	T. dicoccoides Körn.	

The first group is characterized by seven haploid chromosomes, high resistance to or immunity from certain infectious diseases, and extreme incompatibility to crossing with the other two groups. The occasional hybrids obtained have been self-sterile, with a few possible exceptions. The few seeds that have been obtained in the F_1 of crosses between *T. monococcum* and other wheat species are more likely due to back-crosses with wheat pollen than to self-fertilization.

So far as practical breeding of wheat is concerned, *T. monococcum* of the first group can be disregarded. Although a combination of the disease resistance of einkorn with the commercial qualities of common wheat has been frequently advocated and attempted, the project has been entirely without favorable results.

The second group is characterized by 14 haploid chromosomes, and, taken as a whole, by resistance to fungous diseases, such as rust, smut, and mildew. Members of this group can be crossed readily among themselves and with group 3. Hybrids between members of group 2 are completely fertile with a few exceptions, but hybrids between groups 2 and 3 are always more or less sterile.

Group 3 is characterized by 21 haploid chromosomes and by general susceptibility to smut, rust, and mildew. Members of this group can be crossed readily among themselves, the resulting hybrids being completely fertile.

The group of wheats with 21 chromosomes is marked by great varietal diversity and wide adaptation to growing conditions. The varieties included in this group make up the greater part of the commercial wheats of the world. These wheats are the ones principally used for bread and pastry flours. Modern processes of baking have been adapted to the quality of gluten of the common wheats. The maker of light bread utilizes the "hard" wheats to make a large loaf of white bread with high moisture content from a minimum amount of flour, while the "soft" wheats of low gluten content are used in pastry making, because a minimum of shortening is required in producing a soft, flaky product low in moisture content.

The group of wheats with 14 chromosomes is also very diverse in form, as is evident on examination of the various durum, poulard, emmer, Polish, Persian, and wild varieties and forms. When all of these are considered, one may hesitate in accepting the theory of greater variability in the 21-chromosome group. Were it not for the fact that few beardless forms are found in this group, most, if not all, of these probably being the result of rather recent hybridization, the greater diversity of form would probably be ascribed to the group with 14 chromosomes. Again, the more restricted adaptability of the 14-chromosome group is due largely to the fact that very few winter forms are known. Nearly all of the known varieties and strains have the erect habit of growth characteristic of spring wheats. A high degree of cold resistance, a necessary characteristic of winter wheats, is almost entirely lacking in this group. Possibly this may be due to circumstances of origin and recent history of the wheats of this group. Orlov (26) has recently furnished evidence that the durum wheats originated in northern Africa. Possibly they have not been grown outside of warm regions long enough to develop cold-resistant forms.

The durum wheats are used largely for the manufacture of macaroni and other alimentary pastes. Many of these wheats are high in gluten content, higher in fact than most common wheats. Flour from durum wheat is not extensively used, however, in making light bread. Modern baking methods and standards have been adapted to other flours and, despite its higher average protein content, durum wheat flour is looked upon with some disfavor.

The production of durum wheat has increased in the United States from almost nothing 25 years ago to 50,000,000 bushels or more annually at the present time. Were it not for the usually lower market prices of durum wheat, due to the fact that the use of durum products has not been sufficiently developed, much more durum than common wheat probably would be grown in the upper Mississippi Valley, largely because of the greater rust resistance. Smaller production of durum than common wheat is only partially due to the factor of agronomic adaptability.

Although there is some support for the theory (30) that, with increase in chromosome number, there is increase also in variability, adaptability, and economic value of the wheats, and that this can be attributed to a greater opportunity for mutation and consequent advantageous recombinations and attendant effects, the assumption is highly theoretical. It appears to be much more complex, involving many more considerations than those arising from a 14- to 21-chromosome relationship.

It has recently been proposed (8) that there are four sets of seven chromosomes each in *Triticum* and *Aegilops*, a close relative of wheat sometimes included in the genus *Triticum*. According to this theory, einkorn (group 1) has chromosomes set A or B; emmer, durum, Polish, and poulard wheats have A and B; the *vulgare* group, A, B, and C; and *Aegilops*, C and D. The chromosomes in the common wheats and spelt would thus be from the emmer group and *Aegilops*.

This is in keeping with the theory advanced by several (27) that the *vulgare* wheats have their origin from crossings between *Aegilops* and members of the 14-chromosome group of wheats. This proposal is highly theoretical and it appears that the evidence in its favor is of the flimsiest kind. None of the segregates from crosses of *Aegilops* and *Triticum* have furnished any evidence that *vulgare* wheats have originated in this way. Even the recently reported constant hybrids obtained by Tschermak and Bleier (32) in crosses between *Aegilops ovata* and durum and wild wheat are described as intermediate forms. These are fertile and have 28 haploid chromosomes, 14 apparently being from *Aegilops ovata* and 14 from the respective wheat parents. Tschermak suggests that this might be regarded as a new species and believes that it supports the theory of origin of *vulgare* wheat mentioned above. The writer does not share this view, as the experiments on *Aegilops* and wheat crosses with which he has been concerned do not appear to justify this theory.

The matter of disease resistance in the different wheat groups is subject to considerable qualification in the light of present knowledge of physiologic forms of disease organisms. For instance, it is known that many varieties of *vulgare* wheat are resistant to certain forms of stem rust and leaf rust, while varieties of durum wheat are susceptible to certain forms of these rusts. Resistance to mildew also has been found in selections of *vulgare* wheat. It is also known that certain varieties of durum wheat are often quite badly infected with stinking smut, while varieties of *vulgare* wheats are known that are highly resistant to or immune from this disease. In general, however, it appears that members of group 3 are more susceptible than members of group 2 to infection by fungi, but it may be necessary to modify this generalization considerably in the light of increasing knowledge.

HYBRIDIZATION

Almost all of the morphological characters and many of the physiological characters of wheat, oats, and barley have been investigated from a Mendelian standpoint. In crosses between members of the same chromosome group Mendelian segregation occurs usually in 3:1 or 1:2:1 ratios, but sometimes in 15:1 and more rarely in 63:1 ratios. In some instances the characters possessed by parents do not reappear in the progeny in their extreme expression. In other cases transgressive segregation occurs. In crosses between members of different chromosome groups, as between durum and common wheats, many irregularities in segregation are observed. Partial sterility, incompatibility, the non-appearance of expected combinations, and the appearance of new forms are usual.

When relationships are still more distant, as in intergeneric crosses, such as between *Aegilops* and wheat, a few forms involving combinations of parental characters may occasionally appear which remain more or less constant.

In the F_1 complete dominance or recessiveness of certain factors is sometimes reported, but, strictly speaking, some degree of intermediacy is almost universal.

Perhaps the most useful characters, the factors for which have been found to mendelize, are physiologic in nature. Probably the most important of these have to do with resistance and susceptibility to disease. Factors determining resistance to smut, leaf rust, and stem rust have been found to mendelize and are capable of being combined with the factors for various morphological characters. It seems possible, therefore, that disease-resistant forms of various types may be produced.

It has also been found that resistances possessed by differential hosts of physiologic forms of stem rust, and likewise of leaf rust, can be combined, giving segregates resistant to several physiologic forms of the respective diseases. It appears probable that resistance to all forms of leaf rust or stem rust may be obtained by breeding.

Certain other factors determining yield do not appear to mendelize, at least they are highly complex in nature, and the methods of their inheritance have not been determined.

Extensive efforts have been made to combine the rust resistance of wheats of the 14-chromosome group with the milling and baking qualities of wheats with 21 chromosomes. Numerous varieties of durum and emmer have been used in crosses with common wheat. These efforts have been attended with extreme difficulty. Partial sterility in F_1 and later generations has occurred without exception. Homozygous segregates combining the desirable characters of durum or emmer and the common wheats only rarely have been obtained. Even after many years of experimentation no wheat of such parentage has become of commercial importance, although several promising selections are under observation.

In experiments at the Minnesota Station (1), Khapli emmer, which is resistant to all forms of stem rust found in the United States, has been extensively used in crosses with common wheats. The high degree of self-sterility in these crosses, however, led to practical failure. Crosses were then made between Khapli emmer and Mindum durum wheat. Selected F_2 durum segregates were then crossed with Marquis, a spring common wheat. From this latter cross selections have been made that seem to combine the desirable qualities.

The sterility that occurs in hybrids between members of groups of wheats with different chromosome numbers has been explained as due partly to the unbalanced numerical relationships of the chromosomes and partly to incompatibility of certain chromosome combinations. At the time of gamete formation in the F_1 of a hybrid between a 14 and a 21-haploid group, 14 chromosomes appear as bivalents. These may or may not be from the respective parents. The remaining seven chromosomes appear as univalents which pass at random to the gametes. The gametes with 14 and 21 chromosomes apparently are more likely to be functional than those with other numbers, and there results a strong tendency for the production of individuals with 28 and 42 chromosomes. Such individuals usually have the characteristics of *durum* and *vulgare* wheats, respectively.

LINKAGE

Linkage in the small grains has been determined in a number of cases, but it does not appear to have been observed as frequently as the large number of inheritance studies of these plants would seem to justify. The most frequent occurrence of linkage appears to be in barley. Possibly this is related to the fact that barley has the lowest chromosome number (seven), of any of the small grains, with the exception of einkorn and *Avena strigosa.* According to Harlan, linkage between certain characters of barley may appear in one cross and not in another when apparently the same characters are under investigation. Griffee (12) established four linkage groups in barley as the result of certain crosses. Hallquist (14) has studied linkage relationships in barley. Thirteen factors were under investigation, and of the 78 possible combinations, 42 were investigated. Three of these showed strong linkage, while independent inheritance occurred in the others, with the possibility of slight linkage in some cases.

Linkage in barley also has been shown by Ubisch, Vavilov, Nilsson-Ehle, and others.

In oats, Fraser (6) found strong linkage between the fully awned condition and (a) the medium long hairs at the base of the grain, with about 5 % cross-overs, and (b) the Burt type of basal articulation, with about 4% cross-overs.

Linkage between black and gray pigmentation and pubescence of the glumes in wheat has been observed in several experiments. The black color of the glumes was always associated with pubescence in the cross between Black Winter emmer and common wheat reported by Kezer and Boyack (20). Like results were obtained by Percival in a cross of Black Winter emmer and *T. sphaerococcum.* Likewise, in crosses between Black Persian and other wheats reported by Vavilov (33), complete association between the black color and pubescence always occurred. The gray color of *turgidum* and other wheats was linked with pubescence, according to Biffen (3). Other results of similar nature have been reported by Kajanus and by Meunissier.

With the exception of black and gray, the glume colors in wheat behave independently of pubescence in crossing. In wheat, then, there are two types of glume colors, one associated with pubescence, the other not so associated.

Gaines and Carstens (9) recently have reported linkage with about 5% of crossing over between the beard and pubescent-node factors in a cross between two *vulgare* wheats. Love and Craig (24) may have observed a similar phenomenon in a cross between two common wheats. In their experiments beards were very closely linked with pubescent nodes. No bearded plants with glabrous nodes were obtained in F_2, yet in F_3 a few plants of this type were obtained.

A high degree of association has been observed between emmer characters and rust resistance in segregates of crosses between emmer and common wheats, and likewise between durum characters and rust resistance in segregates of crosses between durum and common wheats. Numerous crosses of these kinds have been made to secure rust-resistant common wheats. From the thousands of segregates that have been grown, very few have been obtained combining the good qualities of common and the rust resistance of emmer or durum. Sax (30) reports that, "A very high degree of association was found between chromosome number and morphological and physiological characters in the F_3 segregates (in crosses between *T. vulgare* and *T. durum*). The plants with 14 chromosomes had the morphological characters and susceptibility to rust of the *vulgare* parent." It was also determined by Sax that, "Segregates with an intermediate chromosome number tend to be eliminated because of their sterility and that the ultimate homozygous fertile segregates will have either 14 or 21 chromosomes" Similar results also have been obtained by others.

Malinowski (25) has recently reported that the phenomenon of linkage occurs between the factors determining the sizes and shapes of glumes of wheat when crosses are made between members of the same chromosome group. On the contrary, crossing over between these same factors takes place in crosses between members of different chromosome groups. He suggests that the linkage of these factors is determined by an association between particular chromosomes which are joined in groups moving together as units.

CORRELATIONS

Correlations have been studied quite extensively in the small grains. Usually these studies have dealt with the relationships that exist between characters of the mature plant. Changes in these relationships induced by changes in the environment have been investigated in some instances, and the existence of "fluctuating" and "stable" correlations has been demonstrated. Other studies have been made in which the correlation coefficient has been used as a measure of heredity, the correlation being determined in these cases between characters in the parent and in the progeny.

The study of correlations was previously considered as a valuable aid in plant breeding, but it does not appear that extensive calculations of the coefficients of correlation have been of much assistance in practical plant breeding. However, a knowledge of linkages, which previously have been considered under the head of "genetic correlation" (5), is of considerable practical importance to plant breeders in general. Breeders of the small grains have a vital interest in linkages, as for instance in connection with species crosses.

Correlations between physical characters, such as height and weight of plant, very often have a causal relationship. In such cases high correlations are inevitable, but it is difficult to see how such strictly physical correlations are of use in plant breeding.

Correlations between characters due to the same physiological tendency, on the other hand, may at times have more than incidental importance. Clark (4) found a small positive correlation between awn development and yield in a cross between Kota and Hard Federation. Likewise, Grantham (10, 11), in comparing awned and awnless wheats, found that the awned wheats, under the conditions of his experiments, outyielded the awnless and also tillered more freely and had a smaller variation in yield from year to year. Hayes found in F_3 to F_5 families of crosses between Marquis and Preston wheats that, "Awned families exceeded the awnless families in total yield, percentage of plumpness, and length of seed." Under the conditions of these experiments it may be then, as Hayes (16) concludes that, "The awn of wheat is an important organ, and the tendency to breed only awnless wheats should not be adopted entirely without further experimental studies."

It is essential that the nature and causes of correlations be understood before they are given an important place in plant breeding operations For instance, a high correlation often exists between low kernel weight and protein content in wheat. When low kernel weight is due to underdevelopment, this characteristic is necessarily accompanied by high protein, the two characters being parts of the same physiological phenomenon. In these circumstances low kernel weight would not be a useful character in breeding for a high protein wheat.

SELECTION IN VARIETIES

Selection has been largely used in the breeding of the small grains. Numerous instances could be cited of improved strains developed from a chance selection of an unusual plant, often by a farmer in his own field. Many of the leading varieties of the world have been developed in this way. In many instances the plant selected was evidently the result of natural hybridization, in other instances it may represent a superior strain possibly the result of mutation. According to De Vries (35), the practice of single plant selection was begun with wheat by Le Couteur and Shirreff about a hundred years ago. It was later adopted by other breeders and in time became the prevailing practice. Shirreff emphasized the importance of the initial selection and considered further selection unnecessary. On the other hand, Hallett, an English contemporary, also noted by

De Vries, adopted a system of pedigree culture and attempted to improve on the original selection by repeated selection of the best plant year after year. This best or elite plant was determined by means of elaborate data, and accurate pedigrees were maintained. Although Hallett introduced several varieties, any improvement in them probably was due to the initial selection and not to the elaborate system of reselection employed.

SELECTION IN SELFED LINES

As self-fertilization is the rule in wheat, oats, and barley, it is not to be expected that progress would be made by continuous selection in these crops. Selfed strains are notably constant, as was demonstrated by Johannsen in the pure-line theory. Vilmorin (34) selected within four varieties of wheat for a period of 50 years, choosing annually the best plants as seed stock, without altering appreciably the type or yield of the varieties. Hutcheson (19) reports on selections continued for 13 years in six pure lines of wheat without altering the yielding ability of the sorts. Fruwirth (7) failed to alter certain spikelet characters in a pure line of oats in a nine-year test, and Love and Craig (23) found no effect of selection on height of plant in a four-year test within a pure-line variety of oats.

If selection within a pure line should be effective at times, the result probably would be due to a mutation or a possible chromosome irregularity, rather than the effect of environment or of the selection itself. But changes of this character are so rare that it is a waste of time to continue selection in a selfed line.

Kiesselbach (21) sums up the matter very well in his recent report on extensive selection experiments made in pure lines of Turkey wheat as follows: "Nothing is to be gained by the practice of continued selection within a pure line. All that remains to be done after the initial selection of strains is the further comparative testing for relative excellence."

MASS SELECTION

The selection of a number of heads or plants, the process known as mass selection in distinction to individual selection, has sometimes resulted in increased yield. It is also an effective means of establishing and maintaining uniformity in the crop. The writer once made a mass selection of oat heads of uniform type in a New York farmer's field. The increase from this selection maintained by the farmer has since been in large demand for seed purposes.

When carefully made, a mass selection may consist of a mixture of strains similar in type, or even of a single strain. The tendency, however, is to select heads or plants of a good appearance due usually to favorable environment and not heritable.

MUTATIONS

Perhaps the best example of a mutation within the small grains is the many-noded dwarf barley described by Harlan and Pope (15) and originating in the Mesa variety, a two-rowed naked barley. In oats the spontaneous appearance of the false wild oat in supposedly pure line varieties is believed by the majority of investigators to be due to a mutation, but others hold that the explanation lies in natural crossing. Speltoid types in wheat, the spelt-like heads that are often found both in hybrids and pure cultures of *T. vulgare*, sometimes are considered as mutations, but most of them segregate in unusual ratios, and it is more likely that they are frequently the result of unusual recombinations of factors, although sometimes they may be due to natural crossing.

Types resulting from distant crosses often could be readily mistaken for mutations. Wheat and rye cross naturally as also do wheat and *Aegilops*. From crosses of wheat and rye we have succeeded in isolating strains which in appearance are wheat, except that they possess the hairy or pubescent peduncle of rye even to a degree exceeding any ryes ever observed. From the results of hybridizing species of *Aegilops* with 14 (haploid) chromosomes with members of the emmer group, also with 14 chromosomes, intermediate types, probably impure species, have been obtained which are apparently true-breeding within certain limits. In both examples, were the history of these segregates unknown, they would fulfil the definition of a mutation. The same forms might appear naturally, in fact the wheat-rye segregate is the result of a natural wheat-rye hybrid.

ADAPTATION

Do self-fertilized crops become better adapted to an environment by being grown there over a period of years? Sometimes they appear to do so. Why this occurs is subject to various explanations, usually theoretical. One explanation is that different strains are present in the original material and that through natural selection the ones best adapted become the prevailing forms.

Pissarev (28) reports that in the Government of Irkutsk wheats imported from eastern Siberia have been grown in recent years. These mature rather late and contain a mixture of varieties of *vulgare*, *durum*, and *compactum*. One of these lots of seed was grown by the methods used by the peasants during the five-year period 1913 to

1917. The seed from the previous harvest was used for sowing each year. Changes in the botanical varieties were as follows:

Variety	Percentage of variety present	
	1913	1917
T. vulgare lutescens	72.0	7.6
ferrugineum	10.9	82.4
erythrospermum	9.3	5.7
milturum	6.1	4.3
durum and *compactum*	1.7	0

Natural selection sometimes may be effective in developing a disease-resistant variety. This possibility is illustrated in the experience with the rosette disease in Illinois. Harvest Queen wheat as a variety is very susceptible, yet in a badly infested field certain plants produced heads. These were selected and grown on rosette-infested land. High resistance to the disease was shown by this mass selection which has continued free from the disease since 1919, although grown on badly rosette-infested land. In this case a resistant type was isolated by selection, but if the farmer on whose land this disease occurred had continued to sow his own wheat from year to year back on the same land, increasing resistance to rosette would have been developed in his crop through natural selection of the resistant plants, just as such a strain was isolated by conscious selection of resistant plants.

If disease resistance is present in certain plants of a variety and if the disease is abundant and severe enough, natural selection will be effective in isolating a resistant strain. If resistant plants are not present, the chief hope is mutation, the name we apply to a phenomenon we do not understand.

It has been proposed that the place to look for resistance to a disease is in the area where the disease is endemic. This is on the theory that the plant through long association has somehow developed resistance, or that resistant strains, having been isolated through natural selection in the presence of the disease, are more easily discovered.

There is some evidence, on the other hand, that resistant plants are more likely to be found where the disease is not present. Plants from regions unfavorable to the growth and development of the pathogenic organisms may be more resistant than plants from regions favorable to the organism. In these circumstances, and it is not known how widely this may apply, resistance may not be the result of natural selection or the result of reactions in the plant in the presence of the disease, but rather the failure of the pathogenic organism to adjust itself to the host through lack of association.

CONCLUSION

In the course of the extensive work that has been done in the breeding of the small grains, the theoretical aspects have not been neglected. Genetic principles determined in other investigations have found application in these crops, and in some cases work on the small grains has resulted in valuable contributions in the formulation and development of genetic principles.

Theories developed in the light of partial knowledge have been established, modified, or abandoned as additional facts have been determined. The grouping and relationship of different forms have been especially provocative of theorization. While some of the theories proposed doubtless will be considerably modified in the future they are leading to extensive research along botanic, genetic, physiologic, and cytologic lines. These and other investigations are resulting in the establishment of a large body of facts very helpful in the practical operations in plant breeding.

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2. A PROGRAM FOR SELECTING AND TESTING SMALL GRAINS IN SUCCESSIVE GENERATIONS FOLLOWING HYBRIDIZATION[1]

H. H. Love[2]

Hybrids between varieties or species are usually made either for the purpose of studying the genetic and cytological relations or for practical purposes. It is with the latter point in view that this discussion concerns itself.

Naturally, in order to make the most rapid progress in practical plant hybridization, it is very important that the investigator be well acquainted with the genetic principles involved. To be sure, some valuable practical work has been accomplished without this knowledge, nevertheless, considerable time has been lost by some workers because of the lack of this knowledge. For example, while visiting one of our stations and looking over some wheat hybrids, I asked the one in charge of the project what knowledge he had regarding the inheritance of the several important characters. His answer was that they were not interested in that, but selected the plants approaching their ideal and grew those plants the following year, and so on. At another station one of the workers in charge of cereal improvement was surprised that a plant with white grains came from a cross and assumed that a mixture had occurred, when, as a matter of fact, the occurrence could well be expected and does result in this and similar crosses because of duplicate factors for color.

These, and other cases that might be cited, indicate the desirability of a knowledge of the genetic principles involved in small grain inheritance. Much time may be saved, since in selecting individuals from a lot of hybrids, the plants that are known to be heterozygous would not be selected for seeding another year.

Knowledge of the genetic behavior of the several characters will also be of assistance in determining from the appearance of the F_1 whether one has a hybrid or whether the plants have come from seeds that have been selfed through faulty technic. In this connection it may be well to suggest that when making the cross the parent chosen for the female be so selected that one can be certain by the appearance of the F_1 that a hybrid has been obtained. In wheat, for example, if a cross is to be made between bearded and beardless sorts, it is advisable to use the bearded plant as the female parent, since, under ordinary circumstances, one should obtain a beardless or a nearly beardless type in F_1. If the result is a bearded plant, it is evident that a selfed seed was obtained rather than a crossed one. Other cases may be cited as, for example, a cross between a bronze-chaffed wheat and a white-chaffed variety. Here the white-chaffed sort should be used as the female plant since bronze chaff is dominant, or partially so, over white. With oats, when crosses are made between those with white and those with colored flowering glumes, the white sorts should be selected as the female parents.

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These statements may suggest that some consideration be given to the parent forms that are to be used in making hybrids. Naturally, the investigator should be certain that he is dealing with pure lines. Whenever it is possible, one should choose types from the same species or from species having the same number of chromosomes as considerable sterility may be avoided. While this is not always so, it often happens that when crossing types coming from different species or those having a different chromosome number, many sterile or partly sterile forms are obtained.

When selecting parents to be used in making a certain cross, one is guided by the purpose in mind and the strains that possess the characters it is desired to bring together in one type. It is important to give careful consideration to this matter. For example, it may be important to make a cross looking toward the development of a new, high-yielding, smut-resistant oat. In choosing the parents for this cross one should first select types that are known to give fertile hybrids. Also, whenever possible, care should be taken to select plants that do not have any objectionable characters. For example, the Black Mesdag is a variety that seems to be highly resistant to smut, but it does not yield well and as the kernels are black it should not be used as a parent if white-kernelled types can be found. In most oat-growing sections black oats are objected to and, since in F_2 there will be many more black-kernelled plants than non-black, it is more difficult to obtain the smut-resistant, white-kernelled sort desired.

It is possible to illustrate this by other cases. For example, it may be desirable to produce a white, beardless wheat for the wheat-growing area of New York. In choosing parents for this cross it would be wise to select, if possible, only beardless and white-kernelled sorts. If for any reason, it is necessary to choose a red-kernelled strain, the investigator should try to obtain one that has only a single factor for the red color. Since some of the red wheat strains possess as many as three factors for the red color, we would expect only 1 white-kernelled plant out of 64, and it would therefore be necessary to grow thousands of plants in order to have sufficient white-kernelled types from which to make selections.

In this connection it may not be amiss to emphasize the importance of making these hybrids on a large scale. Often circumstances are such that one is forced to handle small numbers, but it should be kept in mind that whenever possible one should deal with thousands rather than hundreds.

With reference to choice of parents, other examples might be suggested, but those pointed out will indicate the importance of carefully considering the parent forms that are to be used. It should be kept in mind that in all cases the selection should be so made that no undesirable characters are introduced as, for example, the use of a spring wheat in regions where only winter types are adaptable or durum wheats where only *vulgare* varieties are desired. These points with reference to parents emphasize again the importance of a knowledge of the genetic principles involved as well as a knowledge of the behavior in inheritance of the various characters of the cereals.

After the hybrids have been made the details of planting, selecting, and testing must be considered.

The seed from which the F_1 plants are to be grown should be so sown as to give the plants sufficient room for development in order that a large supply of seed may be obtained. These plants should be protected from dangers of mechanical loss, as by livestock and the like.

The plan for planting the F_1 seed for the F_2 generation is to space them so that each plant will have opportunity to develop plenty of seed. The rows should be about a foot apart and the plants spaced 2 inches or more in the row.

If one is directing the work toward high yield, stiffer straw, earliness, or a new type of plant, the seed for the F_2 would be sown merely with the idea of obtaining normally developed plants. On the other hand, if the study involves disease resistance, then it is desirable to subject the plants of F_2 to the disease. For example, if one is attempting to develop a strain of oats that is resistant to smut, it would be advisable to treat the F_1 seed with smut spores before planting. Most of the plants in the resulting F_2 which are readily susceptible to smut will develop smut and need not be carried further. This will reduce the labor by eliminating a large number of plants. This recommendation is made because of the greater difficulty of the more certain method of flower inoculation and for this reason it is well to eliminate many of the plants in F_2. Those plants that do not develop smut may be selected for continuation in F_3 and later generations. Seed inoculation should be made each year until the majority of plants or plant lines have been discarded for one reason or another, then, with the few remaining, flower inoculation can be used. Similar plans may be followed for other studies dealing with disease resistance.

With reference to handling F_3 and later populations with material in other than disease studies, there are at least two methods that have merit. One is line or pedigree selection and the other is mass selection. The former requires that the progeny of each F_2 plant be kept separate and handled as a distinct family, while the latter method calls for a mixing together of the seed from the F_2 and from each succeeding generation.

The method to be followed is largely an individual matter. There are several factors that have an influence on deciding this, such as the amount of available field and laboratory labor, land, whether a wide range of diverse conditions is to be covered, and the like.

If the pedigree method is to be followed, then the plan suggested is to select from the F_2 population those plants that seem to have the desired characteristics and are likely to prove homozygous. Each of these will be given their proper label. There are two ways of handling these for F_3. One is to sow each family separately, spacing the plants in the row so that individuals may be selected for growing in F_4. The second method is to sow the seed from the selected F_2 plants in what may be termed "plant-rows." If time and facilities permit the former method is more satisfactory. It permits a study by families, giving an opportunity to judge from the general appearance whether it is worth while to select many plants from that particular family. It will mean that one will have many more plants for the plant rows than when the selection is made from F_2. It also offers the possibility of determining what families are homozygous.

Whether the plants are selected from the F_2 or F_3 generation for the plant rows, the method for testing will be the same. These plant rows will be sown at a uniform rate of seeding and for comparison a check row will be sown every tenth row. The variety sown in this check row should be a strain of proved value, in fact it is well to use the best strain for the given locality. As mentioned earlier, the rows will be 1 foot apart and the length will depend on the amount of seed available. If large plants have been obtained it is desirable to duplicate the test in another part of the field. This, however, is not often possible, due to the small amount of seed.

If characters other than yield are being observed, it is desirable to have some rows of the parent types interspersed throughout the test. This is important when such qualities as stiffness of straw, resistance to disease, and the like, are being considered, since the parent forms will furnish a means of comparison for the characters in question.

The selection of plants from the F_2 or F_3 generation should be made on a large scale so that a large number of plant rows may be compared at one time.

During the growing season and just before harvest, the rows should be carefully studied to determine the homozygous ones and to take other notes that will be of aid in retaining or discarding strains. It is not advisable to take copious agronomic notes since many of them will be of little value. It is only necessary to take notes that are concerned with the characters that it is desired to obtain in the new type, as, for example, earliness, stiffness of straw, disease resistance, and the like. The bookkeeping should be reduced to a minimum, and it is unwise to collect notes that will prove to be of little value.

Many rows may be compared with the check and discarded in the field. If it seems desirable to continue some of the families that have proved to be heterozygous, selections may be made from these rows for continuation. In such cases it is necessary to select heads rather than plants since the seed was drilled in the row, making it difficult to separate plants. The rows that are to be saved are harvested and threshed. The weight of grain may be taken, but as this is from a single, short row little dependence can be placed on it. From this plant-row test a rather liberal selection of strains should be made for continuing the work another year.

The seed from the plant rows will be sown in rod rows the following year. This may be done by sowing single rows of each sort and then repeating each strain at least one or more times, depending on the amount of seed available. If it is feared that competition between adjacent rows will have an effect, three-row blocks may be sown, but this will usually mean that no replication can be made. This test should have a check row at least every fifth row for the single rows and every third block for the three-row blocks. As in the plant-row test, some rows of the parent strains may be sown for comparison.

The yields are taken on this test and comparisons made with the regular check. A convenient method is to determine the gain or loss that the strain may show over the check, keeping in mind the attendant experimental error. Those that are inferior to the check in yield may be discarded unless they are of value for characters other than yield.

The strains that are saved from this test are continued in a rod-row test the following year in a similar manner, except more replications are grown. It is best to have not less than five single rows of each strain, or, if sown in three-row blocks, to have five three-row blocks of each. The checks are sown as in the test the previous year. This method of testing is continued for three or more years, but more rows are grown in the latter years. The undesirable sorts are gradually eliminated each year until only a few strains remain. These are then tested in three-row blocks replicated nine times with every third block a check.

The strains that give good results in the above tests are put in larger plats sown with a drill under field conditions. These drill plats must be carefully rogued so that all off-type, or undesirable mixtures, may be eliminated. It is also advisable to re-select from these plats so as to be certain that all mixtures are eliminated. From the drill plats multiplication plats are sown and seed obtained for distribution to the grower.

If, instead of using the pedigree method, the seed of the F_2, and succeeding generations, is bulked together and sown each year as mixed seed, the plan differs only in the first few years. The idea is that by having the seed mixed together and grown each year, the weaker, less desirable types are eliminated by environment and after a few years only the more vigorous sorts remain. It is also possible to mix together the seed of several crosses and grow the lot all together. One need not confine the mixture to one cross only.

The plan is to grow such mixtures four or five years before any individual selections are made. Then plants will be selected for plant rows and handled as above outlined. The tests will then be continued in the different years as for pedigree selection.

This latter method has some advantages over the former. There is less detail record-keeping, since there is a smaller number of selections handled than by the former method. If the experimenter is charged with developing strains that will be of value over a wide area, as, for example, different parts of the United States or Canada, then by growing these bulked lots of seed in many different sections of the country, different environmental factors will be encountered. This will result in different types being eliminated at the several trial fields. Here there is an advantage over the pedigree method sometimes followed by doing the early eliminating at one central place and later taking the few remaining strains to different centers for further trial. It is true that possibly the most desirable strain for a given locality may be discarded due to the fact that the first trials may have been conducted under a different set of conditions than exist at the place where the later trials are conducted.

While this method of bulking seed may have the advantages mentioned and possibly others, it is certain that it requires a longer time to carry through than the pedigree system, since after the selections are made the plant-row and other tests must be conducted. There would be no change in the details of testing no matter which method of early elimination is used.

In considering the matter of the time required before the results of a cross are available to the grower the following will indicate how many years must elapse. In bringing this out a short review of the methods of testing will also be given.

The plants for crossing will be grown and the cross made the first year. The F_1 will be grown the second year and the F_2 the third year, unless by the use of a greenhouse some time is saved by growing the F_1 under glass. If selections are made from the F_3 generation, they will be grown in plant rows the fifth year.

During the sixth, seventh, and eighth years the strains will be grown in rod rows and in the ninth year they will be grown in rod rows consisting of three-row blocks. The tenth year the surviving strains will be sown in drill plats and increase plats will be sown the eleventh year. Thus, it will be 12 years, at the least, before any distribution can be made to the growers. This is really a minimum and is on the assumption that this short yield test is sufficient to determine the merit of a variety. If, as some prefer, the selections are not made until the fourth or fifth generation, then one or two more years will be added to the time.

If the bulk method is used the plan for the first three years will be the same as for the pedigree system. Then will follow four or five years of the bulk testing. Suppose this test is continued only over four years. Then will follow the plant-row and other tests, so that by the time seed is ready for distribution 14 years will have elapsed.

The time element must not be ignored by the investigator nor by those in higher authority and it should be recognized that there is no short or quick way to a worth-while result.

For the sake of comparison the two methods are briefly outlined below.

Pedigree Method	Year	Bulk Seed Method
Cross is made.	1	Cross is made.
First generation.	2	First generation.
Second generation.	3	Second and succeeding generations are bulked together and grown for four years at least. (A longer time is preferable.) Then plants are selected.
Third generation is grown and plants selected.	4	
Plant-rows.	5	
Rod rows singly or in blocks of three, checks every fifth row or every third block.	6	
Rod rows, either singly repeated four times or three-row blocks replicated four times, check same as above.	7	Plant-rows.
Rod rows, either singly repeated nine times or three-row blocks repeated nine times, checks as above.	8	Rod rows as under pedigree method.
Three-row blocks repeated nine times, checks as above.	9	Rod rows as under pedigree method.
Drill plats repeated. Frequent checks.	10	Rod rows as under pedigree method.
Increase plats.	11	Three-row blocks as under pedigree method.
Distribution to growers.	12	Drill plats.
	13	Increase plats
	14	Distribution to growers.

This gives in brief the two methods suggested and shows the comparison. It must be remembered that the time indicated is a minumum in each case. If time and facilities are available, it is better to continue the tests longer in each case so as to be certain of the yielding power and other qualities of the strains under test. It is also wise, if possible, to make the selections of plants from the fourth generation rather than earlier, since one is more certain of the homozygous nature of the strains. If selections are made in earlier generations, then it is important, as pointed out, to select heads from the drill plats (or even in the preceding tests) to be certain that one is dealing with a pure strain. It is at once recognized that from the standpoint of yield and some other factors this is not necessary, but from the standpoint of grain grades it is important.

The foregoing merely gives in brief a way to handle selections from hybrids. Many of the details are omitted purposely, since it is understood that others taking part in this symposium will deal with these points.

3. MECHANICAL OPERATIONS OF SMALL GRAIN BREEDING[1]

C. F. NOLL[2]

The methods in use in breeding wheat, oats, and barley, all self-fertilized plants, will be discussed briefly, while rye will be omitted chiefly because almost nothing has been published in this country on the breeding of this crop and the writer has not done any rye breeding. The improvement of these grains by selection and by hybridization will be considered separately.

BREEDING BY SELECTION

By some geneticists selection may not be called breeding, but it is generally agreed that it has been a most effective method of securing improved new varieties. The method is based on the assumption that in any variety of these grains that has been grown for any considerable number of years there are variations or biotypes which may be either better or worse than the average of the strains which together constitute the variety. This was the basis upon which Le Couteur and Shirreff made selections a hundred years ago. The cereal breeder of today with his better facilities can carry on the work on a larger scale than they and can test more accurately.

PLANTS OR HEADS SELECTED

Plants or heads may be selected. Occasionally grains of the commercial variety are spaced so that the plants have more nearly equal chances of development so that the most promising can be selected. More often the selections are made in ordinary fields where plants cannot be easily separated and here heads are taken.

IDEALS IN SELECTION

There may be a question as to whether the selections should be all more or less typical of the variety or whether off-type heads should be chosen. The latter are quite likely to be other varieties that have gotten in by mechanical mixing. The reasonable method, it seems, would be to take desirable plants or heads regardless of variety characteristics. It is of interest to note that some of the outstanding new varieties have been off-type selections, among them Fultz, until lately the leading awnless wheat in Pennsylvania which was selected from an awned variety, and Forward, an awnless wheat originated at Cornell from a head selected in a field of Fulcaster.

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[1] Paper read as a part of the symposium on "Procedure and Results of Small Grain Breeding" at the meeting of the Society held in Philadelphia, Pa., December 31, 1926. Published by permission of the Director as a part of Project 419, Technical Paper 422, Pennsylvania Agricultural Experiment Station, State College, Pa.

[2] Professor of Experimental Agronomy.

It is possible to select with different ideals in mind, depending upon conditions. For example, in years when lodging is common greater stiffness of straw may be looked for, or when diseases are prevalent, such as rusts, scab, etc., one may select for disease resistance, or in winter grains one can select best for winter hardiness when there has been severe winter injury.

The character of grain, of course, can be determined best when the selections are prepared for planting, when those of undesirable type may be eliminated. The number selected is limited only by the facilities of the worker, the chances of success increasing with the number of selections.

MECHANICS OF PLANTING

The rows should be evenly spaced and, for a given test, of the same length. Heads of wheat or barley as selected from the field may not give more than 25 grains each, while those of oats usually have more. Our rule has been to use a 4-foot row for 25 or 30 grains from a head or a plant.

The second year more seed is available and very commonly this is sown in rows approximately a rod long, which are now commonly called rod-rows. In these the rate of seeding is usually the field rate.

For the head- or plant-rows the field should be well prepared and smooth. The rows may be marked with a hand-drawn marker and the furrows made with a wheel hoe. This seems to be the common practice. Love and Craig (14)[3] describe a horse-drawn machine for opening the furrows which greatly reduces the labor if extensive small grain breeding is carried on.

The width and length of the rod-rows vary. At Cornell the uniform width is 1 foot. In order to convert the yield easily into bushels, the length of row for each grain is made so that yields of grain in grams can easily be computed to bushels per acre. Various convenient sizes of row are given by Hayes and Garber (7). We have been making our rod-rows of wheat 16 feet 2 inches long and 9½ inches apart. The yield of grain in grams can then be converted into bushels per acre by dividing by 8. For oats our rows are 16½ feet long and 11½ inches apart. The yield of oats in grams can then be converted into bushels per acre by dividing by 5.

If rows are much narrower than a foot, it is difficult to make them deep enough for planting, and on the other hand, the plants must be crowded in the wide rows if the rate of seeding per given area is to equal the usual field rate.

[3] Reference by number is to "Literature Cited," p. 720.

After the field is furrowed out, the sections or tiers of rows are conveniently marked by stretching strings across the field. Paths of a foot or more in width are left between the sections.

In dry weather furrows may dry out so much before the last are planted that the furrowing should not be much ahead of the planting.

The testing for yield is, in the writer's opinion, the critical part of crop breeding. Our grains have reached a high state of development and one can hardly hope for more than a very few bushels increase over the best varieties already available. Larger gains over varieties in the hands of farmers, however are often secured. To prove conclusively that a new production does or does not give a worth while increase in yield requires very careful testing.

The second year, because of the small quantity of seed available, one is compelled to test in rod-rows or other small plats. After that it is possible to have increasingly larger plats or to continue testing in very small ones.

The Cornell Plant Breeding Department has been using the rod-row system almost entirely in testing small grains for yields and has been the stanchest advocate of this system. According to Love and Craig (13), this method was first used by J. B. Norton of the United States Department of Agriculture. For a detailed description of the system of testing in use at Cornell the reader is referred to a recent paper by Love and Craig (14) appearing in this JOURNAL. Some unquestionable advantages claimed for the system are as follows:

1. The possibility of testing many strains and varieties on a small area.
2. The possibility of having many replications, thereby insuring greater accuracy.
3. The possibility of computing the probable error of the yields secured.

The many investigations on field plat technic have shown that soil is universally heterogeneous and that most dependable results are secured by replication of strains or varieties or of treatments.

Whatever the size of plats, checks should be used. At Cornell the check variety is the best available. At that Station in the second and third year it is sown in every fifth row, and in the fourth year, when each strain or variety occurs in 10 rod-rows in as many parts of the field, it is sown in every tenth row.

At Pennsylvania tests are made in duplicated rod-rows for two or three years. Then the surviving strains are sown in four-drill-row plats 60 to 75 feet long, and from then on in single- or double-drill-row plats 125 to 160 feet long, depending upon the fields available. All these tests are duplicated and a check is sown in every third plat.

HAND VS. MACHINE PLANTING

At most stations planting in plant-rows or in rod-rows is done by hand and the seed covered with a rake, but machines for spacing the kernels accurately have been and may yet be in use at various stations, among which are Minnesota, Michigan, Nebraska, and Indiana. Likewise, drills have been used for sowing rod-rows. Two makes of garden seeders were used at the Pennsylvania Station for rod-row seeding, but they have been given up for hand seeding. A skilled workman with the seed counted out for plant-rows or weighed for rod-rows and placed in properly numbered envelopes can plant or sow the small grains very accurately by hand and can do it more speedily than with machinery, and with little danger of dropping grains in the wrong rows. Love and Craig (13) state that after the rows are marked out five men will sow and cover 2,000 rows in a day.

HARVESTING

The plant-rows cannot be depended upon for yields and in some stations yields are not secured. Many rows will often be discarded on appearance, such as evidence of low yield, injury from disease, weak straw, severe winter injury, etc.

Rod-rows should be tied as cut, tagged with labels prepared beforehand, and then hung in such order in the storage house that all rows of the same strain or variety may be easily found and threshed in succession. Taken directly from the field and hung separately with the heads down, there is little danger of grain getting from one bundle into the others. Where a good storage house is lacking the bundles may be shocked together and the shock covered with canvas. Tying the heads of each bundle in cloth may be done to avoid loss of grain and prevent mixing.

At a few stations the yield of sown plats is secured by cutting out samples of a square yard each and threshing these instead of the whole crop.

THRESHING

With the testing of grains in small plats has come the need for machines which would thresh the small lots satisfactorily. The chief requirements of such small threshers are that they thresh clean without injuring the grain, that they do not retain grains and thereby cause mixing, and that they can easily be opened and cleaned. To the writer's knowledge there are no purely commercially-made machines on the market, but a number of experiment stations are using threshers designed by cereal breeders. The Cornell Plant Breeding Department (14) has been using a machine for rod-row bundles and larger lots designed by H. W. Teeter of that Department. The straw is run through this. Other machines are intended to thresh the heads cut from the straw or to thresh only the heads when the head end of the bundle is thrust into the cylinder. Such machines for threshing bundles from rod-rows are used at a good many of the experiment stations. The Pennsylvania Station is using one designed by Nickolas Schmitz. Teeter also designed a smaller machine (13) for threshing single plants or heads and Hoffman (9) of the University of California has described a machine for threshing single heads.

ROGUING

Whatever the method of testing new strains, there is certain to be some mchanical mixing requiring roguing if a pure variety is to be distributed. It is better to sow special plats for roguing than to do extensive roguing in the plats grown for yield tests. Seed from the rogued plats should be used for the increase plats.

HYBRIDIZATION

Though most improved new varieties have originated as selections, the breeders isolating strains that have appeared naturally, nearly all small grain breeders are resorting to hybridizing.

EMASCULATING

Emasculating should be done with the minimum of injury to the flowers. Even at the risk of some selfing, it is well to wait until the anthers are nearly ripe. The anthers should not be crushed when removed for fear of selfing the flowers. Usually, only a portion of the flowers of a spike are emasculated, the others being cut off. In the case of wheat and barley the flowers of the middle part of the head are retained and of these only the outside flowers of the wheat spikelets. Where the atmosphere is not too dry the ends of the glumes may be cut off and the anthers removed and pollination effected without opening the glumes. For greater ease in working the awns, if present, should be removed.

BAGGING

Few, if any, modern cereal breeders would let the emasculated spikes remain uncovered. Früwirth (5), Frear (4), and Leighty and Hutcheson (12) have reported in their different tests that 40 to 90% of emasculated wheat flowers left uncovered set seed, indicating the danger of natural crossing in the interim between emasculation and pollination.

POLLINATION

The failure to secure a high percentage of fertilization may at times be due to taking immature anthers. Mature anthers may be inserted into the flowers before they dehisce; or, if held in the hand or exposed to the sun a few minutes until they dehisce, the pollen may be transferred with a brush.

Emasculated flowers properly protected will remain receptive for some days. Salmon (17) reported that wheat flowers emasculated and not fertilized remained open until the stigmas began to die in eight to ten days.

Anthony and Harlan (1) emasculated barley flowers the day before they thought they would have been fertilized. Then, to determine how long the stigmas would remain receptive, they pollinated 40 flowers on each of six successive days. The stigmas were most receptive the second day, or a day after they would have been naturally fertilized, after which the percentage of successful pollinations decreased rapidly until the sixth day when no pollinations were successful. Pollen can be held only with difficulty. Where two varieties differing in time of blooming are to be crossed, there should be a succession of plantings of the earlier variety at short intervals after the later has been planted so that one can have the two in flower at the same time.

Pollinations are most likely to be successful when the pollen parents are blooming. Anthony and Harlan (1) make the statement that a study of the conditions governing fertilization in nature shows that conditions unfavorable to fertilization are also unfavorable to progress in the development of pollen and vice versa.

Unfavorable weather conditions may retard the blooming. Anthony and Harlan (1) state that there may be little fertilization in barley for two or three cold wet days.

There have been some investigations on the time of day in which blooming takes place. Anthony and Harlan (1) found that on clear days barley anthers dehisced in the morning following rapid evapo ration from the plant and that there was little fertilization from the morning until late in the afternoon.

Hays (6) stated that wheat flowers usuallv opened at dawn and closed within an hour, but Leighty and Hutcheson (12) found at the Minnesota Station and at the Arlington, Va., farm that blooming of wheat was to some extent continuous during the 24 hours with nearly the same number blooming at night as in the day and nearly the same number in the afternoon as in the forenoon. They observed two periods of extensive blooming during the day time, one from about 7 to 9 in the morning and the other about the middle of the afternoon.

Kirchner (11), Norton (16), and Hayes and Garber (7) reported that oats bloomed chiefly in the afternoon, the last investigators observing that most oat flowers bloomed late in the afternoon.

Love and Craig (14) mention that among the advantages of growing the grains that are to be crossed in the greenhouse are that pollen can be collected for a longer time during the day and that the emasculated flowers are not so likely to dry up.

In this connection it should be mentioned that crossing can be accomplished by tying a head of the pollen parent, when the flowers are ready to bloom, to the emasculated head and covering the two with one bag. Hayes and Garber (7) refer to Jellneck's (10) experiments in which he secured much better results in wheat by this method than by transferring a ripe anther to each flower.

If there is a choice, it is desirable to use for the pollen parent the variety that has easily observed dominant characters such as absence of awns, brown chaff, and purple straw in wheat, colored glumes in oats, and absence of awns and black or purple pale as in barley. When the pollen parent carries the dominant character, the plants from selfed seed can be easily detected among the F_1 plants.

DISINFECTING SEED

It is a difficult task to treat many small lots of seed for diseases. Dusting is more convenient than treatment with liquids. A simply constructed small rotary box duster is described by Hoffman (8).

INOCULATING FOR DISEASE AND DISINFECTING

Durrell and Parker (3) compared methods of inoculation for rust and secured best general infection by blowing dry spores on the plants with a spore blower. Grains can easily be inoculated for the smuts of oats, stinking smut of wheat, and covered smut of barley by shaking the grains and spores together.

They found counting of rust sori more accurate by use of glass etched in one-fourth centimeter squares than by estimating degrees of rust by the scale devised by N. A. Cobb of Australia.

Barney (2) found no advantage in soaking oat grains before inoculating for loose smut.

RECORDING NOTES

The systems of keeping records vary a good deal. The numbering should be simple and yet make it possible to find easily the history of any strain and the record of its performance.

At the Pennsylvania Station the selections are numbered from the rows in which they are first planted. These numbers are followed by a dash and the last two figures of the year in which the first planting is made. Thus, the selections of oats planted for the first in 1926 were numbered 1–26, 2–26, etc. These numbers are retained until the selections are discarded or named.

The crosses are numbered in order with the letter X added to each serial number. Crosses between different plants of the same varieties are given different hybrid numbers. These numbers are used for the F_1 plants. In the next generation the individual plants that are saved are designated by Arabic numerals preceded by dashes. Thus the F_2 plants of cross 35x retained for further planting would be numbered 35x–1, 35x–2, etc. Plants of succeeding generations are numbered by adding numbers to the pedigree numbers of the respective parent plants.

When homozygous strains are secured from hybrids they are planted in rod-rows and then they are numbered serially in agreement with the number of the rod-rows in which first planted with the letter *a*, and followed by a dash and the last two figures of the year in which they are first planted in rod-rows. The homozygous strains of oats from hybrid origin first planted in rod-rows in 1926 have now the following permanent numbers: 2a-26, 3a–26, 5a–26, etc., rows 1 and 4 being checks.

It hardly seems worthwhile to take detailed descriptive notes on all selections or hybrids handled unless of the latter for inheritance studies, but accurate agronomic notes, as well as careful botanical descriptions, of promising thoroughly tested new strains should be recorded.

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4. WHAT HAS BEEN ACCOMPLISHED BY BREEDING SMALL GRAINS?[1]

R. J. GARBER[2]

During the past few decades considerable time, thought, and money have been given to the improvement of small grains. What is the net result? Have we obtained a measurable increase in yield? Is the quality of the small grains which we are now growing superior to that of those grown by our forefathers? The cereal breeders undoubtedly have achieved some results which are not directly measurable in terms of increased yields or improved qualities, but which are nevertheless of great value to mankind.

Sometimes we forge ahead with too little regard for the past. Occassionally, it is well to pause and look back as by so doing we may improve our perspective and our method of work. The annual reports of the United States Commissioner of Patents, issued about 75 years ago, contain many interesting references to agriculture. It will be recalled that at that early period there was no federal Department of Agriculture. The sections of the reports which concern agricultural practices are made up largely of clippings from the agricultural journals of the day and quotations from recognized authorities on agriculture. On page 142 of the Annual Report for 1845 (Ex. Doc. No. 140), the following treatment is suggested for the control of smut in wheat, "One or two days before sowing put the seed into a vat or box, then take strong brine (such as is used for preserving meat) and heat it as hot as you can bear the hand in, for five seconds, and pour this over the wheat, stirring this in the meantime with a scoop or shovel till the whole is completely wet; two or three quarts of brine is sufficient for a bushel of wheat; let it stand a few hours to drain, then spread it on the barn floor and sprinkle it over with fine slaked lime; stir it and add lime until every kernel appears white and dry; it is then fit for sowing."

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[1] Paper read as a part of the symposium on "Procedure and Results of Small Grain Breeding" at the meeting of the Society held in Philadelphia, Pa., December 31, 1926. Approved for publication as Scientific Paper No. 34, by the Director of the West Virginia Agricultural Experiment Station, Morgantown, W. Va.

[2] Agronomist.

On page 420 of the same report the following treatment is suggested for the control of wheat rust, "To prevent this latter malady (rust), Mr. Haywood, of Buffalo, has used charcoal with signal success. He has kindly furnished us with a plot of seven wheat fields (near Sandusky, Ohio) taken for experiments this season, with the results which follow:

"No. 1—20 acres; applied fifty bushels of coal, ground fine, per acre; yield 25 bushels per acre.

"No. 2—4 acres; no coal applied; wheat badly rusted; yield 5 bushels per acre.

"No. 3—15 acres; coal as in No. 1; yield 25 bushels per acre.

"No. 4- 25 acres as in No. 1; yield 35 bushels per acre.

"No. 5—15 acres; coal; yield 25 bushels per acre.

"No. 6—8 acres; no coal; yield 5 bushels per acre.

"No. 7—6 acres; no coal; yield 3 bushels per acre.

"Note:—No. 4 was seeded with old wheat.

"The soil, culture, etc., were precisely alike, except the use of 50 bushels of coal per acre, as designated—sown in April and May. The soil abounds in lime and organic matter."

Another remedy for rust is suggested on page 108 of the Annual Report of the Commissioner of Patents for the year 1847 (Ex. Doc. No. 54), as follows, "One writer, we notice attributes rust to fog, and advised unless protected by woods, etc., that there should be a high tight board fence in the direction towards which the fog originates. Another views it as the result of a vigorous growth of wheat in the latter part of winter or early spring, and that in these circumstances the energies of the root having been exhausted at the time when the grain began to form, and the grain having failed for want of support,—if followed by wet weather—the black rust or smut is produced, or if by dry weather the red rust."

Suggestions for the control of the Hessian fly may be found on page

110 of the same report, as follows, "Take orpiment (which can be procured at any druggist's) and with lighted charcoal, burn the orpiment close to the wheat, anytime after sunset or before sunrise; at the time when the plant commences to flower it should be repeated, while the fly is found to exist.

"Another and perhaps equally efficacious remedy.—So soon as the fly is discovered, or so soon as the plant shows a disposition to open its florets, carry around the patch of wheat strong lights at night, and the darker the better—the flies will all rush to the fires and destroy themselves."

The above quotations are a few of the many interesting ones which might be taken from the agricultural writing of 75 years ago. Contrast these views and practices with those which obtain at present. The cereal breeder in cooperation with the plant pathologist and the entomologist has learned how to combat rust and smut and even the Hessian fly. The pathologist and entomologist have discovered means of control for smut, for the Hessian fly, and, to some extent, for rust other than by breeding, but perhaps the most satisfactory control is to produce, wherever possible, a resistant host. Considerable progress in this field has been made and the future looks promising.

The small grain breeder has contributed his share to our present knowledge of the fundamental principles of heredity. The literature recording the manner of inheritance of specific characters in wheat, oats, and barley is voluminous and serves to corroborate and to extend the principles of inheritance announced by Mendel. The principle of multiple factor inheritance was discovered by a cereal breeder. It is hardly necessary to elaborate on the importance of this discovery other than to state that the inheritance of many quantitative and qualitative characters are explained on this basis. The pure line concept of Johannsen has been verified many times in cereal breeding. The discovery of different biological forms of rust was made possible by the application of this concept to cereals and to rusts. Likewise, our present notion of a commercial variety of wheat, oats, or barley is founded on the pure line concept. Plant breeders have recognized for some time that varietal experiments conducted at different stations are not comparable unless the several varieties belong to the same pure lines, a fact which has not been as generally accepted as is desirable. The cereal breeder has helped to raise the standards of farming and incidentally has helped the farmer to derive a greater source of satisfaction from his work. Where is the farmer who does not get a certain amount of satisfaction from

TABLE I.—*Total wheat acreage and estimated acreage of several improved varieties of wheat in certain states in 1926 in terms of 1,000 acres.*

State	Variety Name	Acreage	Total wheat acreage[a]
Colorado	Kanred	250	1,254
	Blackhull	3	
	Marquis	200	
	Defiance	10	
Illinois	Ilred	77	2,269
Indiana	Michikof Purkof	200	1,738
Iowa	Kanred	35	433
	Iowa 404	21	
	Iobred	5	
Montana	Marquis	2,873	3,192
	Mont. 36	20	
	Karmont	30	
Minnesota	Marquis	1,200	1,958
	Kota	100	
	Ruby	100	
	Mindum	110	
	Minturki	140	
New York	Forward	20	317
	Honor	50	
	Junior No. 6	200	
Utah	Kanred Utah Sel.	40	217
	Dicklow	50	
	Federation	10	
Virginia	V. P. I. 131	300	630
	V. P. I. 112	50	
Idaho	Federation	35	876
	Mosida	5	
Kansas	Kanred	2,000	9,209
	Blackhull	4,000	
Kentucky	Ashland	25	218
	Trumbull	20	
	Kentucky 47	5	
Maryland	Mammoth Red. Sel.	120	515
	Currell Sel.	50	
	Penna. 44	10	
	Leap	120	
N. Dakota	Marquis	4,404	9,052
	Kota	411	
	Imp. durums	800	
Ohio	Trumbull	919	1,727
	Fulhio	144	
	Gladden	61	
Oregon	Hybrid 128	150	900
	Federation	125	
	Hybrid 123	8	
S. Dakota	Marquis	904	2,577
	Kota	904	
	Acme	309	
Nebraska	Nebr. 60 Nebr. 6 Kanred Marquis	2,000	2,868

Washington	Hybrid 128	300	1,961	Oklahoma	Kanred	600	3,502
	Triplet	100			Blackhull	2,100	
	Ridit	150					
	Hybrid 123	100					

Total wheat in above-named states.............................. 45,413

Total improved.. 26,973 = 59.4% of total acreage.

Total Marquis... 9,581 = 35.5% of improved acreage, except Nebraska.

Total Kanred.. 2,885 = 10.7% of improved acreage, except Utah and Nebraska.

Total Blackhull... 6,103 = 22.6% of improved acreage.

Total wheat in U. S.................... 52,282

[a]The figures in this column are averages of the yields for 1924 and 1925 as given in the U. S. D. A. Yearbook for 1925.

growing a pure variety of grain, particularly if that pure variety is superior in yield and quality? Every spring wheat farmer knows that it is more gratifying to produce Marquis than Humpback. The above are only a few of the many more or less intangible contributions which the small grain breeder has made, but my main purpose here is to offer some evidence which indicates the magnitude of the increase in yields which has resulted in relatively recent years from cereal breeding.

IMPROVED SMALL GRAINS IN THE UNITED STATES

In order to get first hand information, a questionnaire was sent to several persons[3] in the United States and the analysis which follows is based largely on the replies received. In some cases the data are statistical, in other cases they are based on experimental evidence, and in still other cases they are at best rough estimates. These facts should be borne in mind in the subsequent discussion.

Information was requested concerning the relative area occupied by improved small grains (wheat, oats, barley, and rye) in each of several states. In some cases this information was requested of cereal breeders, in others of crop production specialists, and in still others of both groups of workers. In practically all instances a reply to a questionnaire represented the combined opinion of several persons. Where more than one reply was received from a single state the results were averaged. Information was also requested regarding the relative yield of the improved forms compared with the varieties commonly grown. The increased yields, if any, together with the estimated acreage of the improved varieties gives one at least an approximate idea of the value of the new form to the farmer. The data for the total areas of a crop in a certain state were taken from the *Yearbook* of the United States Department of Agriculture for 1925. An inquiry was also made relative to the aims in cereal breeding. Each person to whom a questionnaire was sent was asked to name in order of importance the lines along which the improvement of small grains is sought at present.

WHEAT

The relative acreage occupied by improved varieties of wheat in certain states is shown in Table 1. It should be kept in mind that the acreages of improved sorts presented are estimates, but even as such they may be accepted as an indication of the importance of new forms which have been originated for the most part in relatively recent years.

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[3] The writer acknowledges with pleasure the kindly cooperation of the several persons who supplied the information requested in the questionnaire.

The total average acreage of wheat for the years 1924 and 1925 in the states named in the table is about 45 million, whereas the total estimated acreage in improved varieties is about 27 million, or about 59%. Of the total acreage in improved varieties, it is estimated that Marquis occupies over 9 million acres, or 35%; Blackhull over 6 million acres, or 22%; and Kanred about 3 million acres, or 10%. For comparison, the total area in wheat in the United States is shown at the bottom of the table. It will be observed that the total wheat in the states under discussion represents over four-fifths of that in the United States.

The fact that these new forms have been rather widely accepted is *prima facie* evidence that they possess characteristics superior to those of the forms supplanted and in most cases one of the superior characteristics is increased yield for it is in this that farmers are most generally interested. To measure accurately the increase in yield which has resulted from the introduction of new forms in general is difficult. There are data, however, which show the increase that has resulted from the introduction of particular new varieties in certain regions. The data from Kansas and Minnesota, presented in Table 2, are the result of cooperative varietal experiments conducted with farmers, whereas the data from Ohio are from threshermen's records.

TABLE 2.—*The yield of improved varieties of wheat compared with those commonly grown.*

State	Number of tests	Duration of test	Varieties	Yield per acre in bushels	Difference in bushels
Kansas[a]	242	4 years	Kanred	——	+3.6
			Average of local varieties, mostly Turkey	——	——
Minnesota	8	1 year	Minturki	29.3	+5.6
			Average of local varieties	23.7	——
Ohio	1,700[b]	2 years	New varieties	22.4[c]	+4.0
(six counties)			Average of other varieties	18.4	——

[a] Data from Kan. Agr. Exp. Sta. Cir. 74. 1919.

[b] Approximately one-half of fields seeded to new varieties (Trumbull, Fulhio, Gladden, and Ohio 9920).

[c] Yields taken from threshermen's records.

The cooperative experiments in Kansas undoubtedly have demonstrated the superior yielding capacity of Kanred over Turkey. If the average difference in yield per acre between these two varieties is multiplied by the approximate present acreage (about 2 million) of Kanred, one may gain some idea of what the introduction of this variety has meant to the Kansas farmers. Another selection from Turkey wheat which is grown widely in Kansas is Blackhull. Something over 200 cooperative experiments conducted over a period of four years have shown that this variety is a slightly higher yielder than Kanred in most localities except where winter killing is severe. If one accepts the estimated present acreage of Blackhull as 4 million and of Kanred as 2 million, a conservative valuation of the net annual gain that has resulted to the Kansas farmers from the introduction of these two forms is 17 million dollars.

In the Ohio experiments it is not possible to make so direct a comparison between the new varieties and the ones replaced, since they were grown on different fields. It should also be pointed out that the farmers growing the Trumbull, Fulhio, Gladden, and Ohio 9920 varieties are perhaps on the average somewhat more progressive and better farmers than those growing the older varieties. Of course, in those cases where the same farmers grew both old and new varieties this objection could not be made. Regardless of whether the above criticisms are valid or not, the data do show that on the average the farmers who seeded their fields to the new varieties realized about 4 bushels per acre more than did the farmers who seeded other varieties.

The Minnesota data are for 1926 and are based on eight tests only, but they indicate a considerably greater yielding capacity for Minturki than for the local varieties of winter wheat.

These experiments will serve as concrete demonstrations of the increase in yield which has resulted from the use of improved varieties of wheat. Other similar experiments with similar results have been carried on elsewhere.

In addition to the cooperative experiments with farmers, there have been very many carefully planned and conducted varietal trials at experiment stations which have proved the superior yielding capacity of improved forms. However, these experiments do not give a very adequate measure of increase in yield of the improved forms over the ones they are expected to replace. This is true for two reasons. It is almost impossible to test the new forms for all the soil and climatic conditions they will be grown under, and moreover, it is difficult to measure the average yielding capacity of the old varieties which it is expected will be replaced. There is perhaps a need for testing new forms under a greater range of conditions than has been done in the past. In the last analysis, the readiness with which a new variety of wheat is accepted by the miller and the extent to which it is grown by the farmer show the real measure of its success.

TABLE 3.—*Total oat acreage and estimated acreage of several improved varieties of oats in certain states in 1926 in terms of 1,000 acres.*

State	Variety Name	Acreage	Total oat acreage[a]	State	Variety Name	Acreage	Total oat acreage[a]
California	Kanota	10	118	Montana	Victory	300	604
Colorado	Colorado 37	50	231		Markton	6	
	Nebraska 21	25		Minnesota	Victory	900	4,721
Iowa	Albion (Ia. 103)	1,477	5,972		Gopher	800	
	Rich. (Ia. 105)	534			Improved Ligowa	400	
	Iowar	885			Iowar	225	
	Iogren	25		New York	Cornellian	150	1,010
Idaho	Idamine	50	162		Victory	150	
Kansas	Kanota	1,000	1,540		Oher varieties	100	
Kentucky	Albion (Ia. 103)	5	241	Ohio	Miami	300	1,873
S. Dakota	Cole	190	2,918	Oregon	Markton	10	300
	Richland	190		Texas	Frazier	30	1,273
Nebraska	Improved varieties	1,600	2,577		Nortex	1	
	(mostly Neb. 21)			Virginia	V. P. I. No. 1	20	248
Illinois	Albion	500	4,549	Washington	Markton	50	214
Oklahoma	Kanota	300	1,170				

Total oats in above-named states 29,721
Total improved .... 10,283 = 34.6% of total acreage.
Total Albion .... 1,982 = 19.3% of improved acreage.
Total Victory .... 1,350 = 13.1% of improved acreage.
Total Kanota .... 1,310 = 12.7% of improved acreage.
Total oats in U. S 43,958

[a] The figures in this column are averages of the yields for 1924 and 1925 as shown in the U. S. D. A. Yearbook for 1925.

In addition to increased yield considerable progress has been made in breeding wheat for resistance to stem rust and bunt smut. It will not be possible to discuss in this paper the extensive work that has been done and that is now under way in breeding wheat for disease resistance, but this seems to be one of the most promising lines of endeavor. Milling quality, strength of straw, and winter hardiness are three other characters of wheat which have been improved but in which there still remains much to accomplish.

OATS

The relative acreage occupied by improved varieties of oats in certain states is shown in Table 3. The data recorded were obtained in a manner entirely similar to that for wheat.

The total average acreage of oats for the years 1924 and 1925 in the states named in Table 3 was 30 million, or about three-fourths of the total average acreage of oats in the entire United States for the same two years. Of the total oat acreage in the states named in the table, it was estimated that about 10 million acres, or about one-third, were seeded to improved varieties. It was further estimated

TABLE 4.—*The yield of improved varieties of oats compared with those commonly grown.*

State	Number of tests	Duration of test	Varieties	Yield per acre in bushels	Difference in bushels
Iowa[a]	46	5 years	Richland (Ia. 105)	56.4	+1.3
			Kherson	55.1	——
	66	5 years	Albion (Ia. 103)	54.1	+3.0
			Kherson	51.1	——
	267	5 years	Albion	50.7	+4.4
			Average of local varieties	46.3	——
	344	5 years	Iowar	50.0	+5.8
			Average of local varieties	44.2	——
	111	5 years	Iogren	49.3	+3.6
			Average of local varieties	45.7	——
Minnesota	35	1 year	Gopher	56.4	+8.7
			Average of local varieties	47.7	——
Oklahoma	6	1 year	Kanota	36.2	+8.3
			Average of local varieties	27.9	——
	8	1 year	Kanota	41.9	+6.8
			Red Texas	35.1	——
Kansas[b]	6	1 year	Kanota	45.2	+15.3
			Local Red Texas	29.9	——
	25	1 year	Kanota	45.0	+6.7
			Local, in most cases Red Texas	38.3	——

[a] Data from U. S. D. A. Bul. 1343. 1925.

[b] Data from Kan. Agr. Exp. Sta. Circ. 91. 1921.

TABLE 5.—*Total barley acreage and estimated acreage of several improved varieties of barley in certain states in 1926 in terms of 1,000 acres.*

State	Variety Name	Acreage	Total barley acreage[a]	State	Variety Name	Acreage	Total barley acreage[a]
California	Sacramento	50	869	Oklahoma	Wis. Winter	75	167
Colorado	Colsess	20	368		Oklahoma	6	
	Trebi	20		New York	Alpha	60	151
	Coast Sel.	10			Wis. Ped.	30	
Iowa	Ontario 21	10	160		Feath. No. 7	10	
Idaho	Trebi	25	121	Oregon	Hannchen	10	80
Montana	Trebi	30	130		Other vars.	5	
	Hannchen	8		Tennessee	Five and Six	15	21
Minnesota	Manchuria 184	450	1,022	Washington	Beldi	30	80
	Minsturdi	60			White Winter	10	
	Svansota	5		Wisconsin	Wis. Ped.	400	426
	Velvet	1		Nebraska	Oderbrucker	95	242
					Minn. 184		

Total barley in above-named states.................................... 3,837
Total improved.................................... 1,435 = 37.4% of total acreage.
Total barley in U. S.................................... 7,550

[a] The figures in this column are averages of the yields for 1924 and 1925 as shown in the U. S. D. A. *Yearbook* for 1925.

that approximately 19%, or about 2 million acres, was seeded to Albion; 13%, or somewhat less than 1½ million acres, to Victory; and a slightly less area to Kanota.

As in the case of wheat, there are data available which show the increase in yield which has resulted from the introduction of new varieties of oats in certain states. The data presented in Table 4 are the results of cooperative varietal experiments conducted with farmers.

The last column of the table shows differences in bushels per acre between the average yields of certain new strains of oats and locally grown varieties. The differences range from 3.6 to 15.3 bushels per acre in favor of the improved sorts. The cooperative experiments reported are numerous enough and are scattered over a sufficiently large area to offer a rather convincing demonstration of the superiority in yield of the improved forms over the local sorts. The Iowa experiments also demonstrated the greater yielding capacity of Richland and Albion over Kherson, the variety from which they were selected.

BARLEY

The total barley acreage and the estimated acreage of improved barley in certain states are shown in Table 5. The former is given as somewhat less than 4 million acres, and of this it is estimated that approximately 1½ million acres, or a little over one-third, is seeded to improved forms. The total area in barley in the United States is about 7½ million acres.

In 1926 the Minnesota Experiment Station carried on 38 cooperative varietal trials in which Velvet, a new variety of barley, was compared with the varieties grown locally. The average yield of the local varieties was 6.7 bushels less than the average yield of Velvet.

RYE

Less attention has been given to the improvement of rye than to the other small grains. However, several improved varieties have been produced in the United States which have been quite widely distributed. The reports received from eight different states in which considerable rye is grown indicate that Rosen is by far the most widely distributed. It is estimated that 95% of the total rye acreage of Michigan is seeded to this variety. Among the other improved varieties which are prominent in one or more states may be mentioned Minnesota No. 2, Dakold, and Wisconsin Pedigree.

TABLE 6.—*Total wheat acreage and estimated acreage of several varieties of wheat in Canada in 1926 in terms of 1,000 acres.*

Province	Estimated acreage in													
	Marquis	Red Fife	Ruby	Mindum	Huron	Sun	Preston	Red Bobs and Selections	Renfrew	Garnet	Dawson's Golden Chaff	O.A.C. No. 144	Kharkov	Total wheat acreage[a]
Prince Edward Island	22	1	..	..	..	..	..	..	..	..	..	..	..	31
Nova Scotia	9	1	..	..	..	..	..	..	..	..	..	..	..	12
New Brunswick	8	1	..	..	..	..	..	..	..	..	..	..	..	16
Quebec	50	10	..	..	12	..	1	..	..	..	..	..	..	96
Ontario	80	6	..	..	8	..	..	..	..	..	500	30	..	864
Manitoba	2,200	2	10	8	..	..	..	..	..	4	..	..	..	2,834
Saskatchewan	11,000	3	..	1	..	..	10	15	1	4	..	..	..	12,719
Alberta	4,000	1	10	..	..	..	1	15	10	2	..	..	5	5,504
British Columbia	1	1	..	..	..	10	..	..	..	..	..	..	1	46
All Canada	17,370	26	20	9	20	10	12	30	11	10	500	30	6	22,122

[a] From Monthly Bulletin, Agricultural Statistics, Ottawa, Jan. 1926.

IMPROVED SMALL GRAINS IN CANADA

The Dominion of Canada grows annually a vast amount of wheat and oats and a considerable amount of barley. Two plant breeders of that country have the distinction of together originating one of the most successful new forms of spring wheat that has ever been produced.

The discussion below is based largely on information kindly supplied by L. H. Newman, Dominion Cerealist. The acreages of the several varieties of small grains listed in the tables are necessarily estimates, but even as such they are indicative of the relative position occupied by the varieties at present.

WHEAT

The total wheat acreage, together with the estimated acreage of several important varieties, are shown in Table 6. The old standard variety, Red Fife, is included in order to show to what extent it has been replaced by improved sorts. The acreages recorded at the bottom of the table are of most interest in the present discussion. Out of a total of approximately 22 million acres of wheat in Canada, it is estimated that 17 million, or about 77%, is seeded to the Marquis variety. It has been estimated that 90% of the wheat grown in western Canada is Marquis. This, together with its wide distribution throughout the spring wheat belt of the United States, is a striking tribute to the merits of Marquis, particularly when one considers that it was introduced to the farmer only 20 years ago.

It is interesting to compute the probable increased yields for the farmers of Canada that have resulted from the distribution of this variety. Fortunately, there are data on relative yields which aid in making such a computation. In Table 7 are shown the average yields of Marquis and of Red Fife determined at different places in Canada.

TABLE 7.—*Average yields of Marquis and Red Fife at different places in Canada.*

Where grown	Number of years	Average yield in bushels Marquis	Average yield in bushels Red Fife	Difference in bushels
Ottawa, Ont.	9	36.5	27.8	+8.7
Brandon, Man.	6	35.7	26.7	+9.0
Indian Head, Sask.	6	34.1	27.5	+6.6
Rosthern, Sask.	5	28.6	28.4	+0.2
Scott, Sask.	6	22.4	23.5	—1.1
Average				+4.7

In the last column of Table 7 the average difference in yield between the two varieties grown at the five places during the time indicated is 4.7 bushels in favor of Marquis. On the basis of this

TABLE 8.—*Total oats acreage and estimated acreage of several varieties of oats in Canada in 1926, in terms of 1,000 acres.*

Province	Estimated acreage in Banner and Selections	Victory	Gold Rain	Abundance	O.A.C. 72	O.A.C. 144	O.A.C. No. 3	Alaska	Total oat acreage[a]
Prince Edward Island.	130	5	..	..	..	..	..	..	173
Nova Scotia.........	90	4	1	..	..	..	.	..	122
New Brunswick......	120	10	5	..	..	..	..	..	248
Quebec..............	1,500	100	6	..	..	..	..	9	1,970
Ontario..............	1,500	5	2	..	900	1	50	5	2,964
Manitoba............	1,200	300	50	1	..	.	..	..	1,880
Saskatchewan........	3,500	800	3	10	1	.	..	..	4,980
Alberta..............	1,200	700	..	3	..	..	..	..	2,073
British Columbia.....	20	20	1	..	..	..	.	..	63
All Canada..........	9,260	1,944	68	14	901	1	50	14	14,473

[a]From Monthly Bulletin, Agricultural Statistics, Ottawa, Jan. 1926.

TABLE 9.—*Total barley acreage and estimated acreage of several varieties of barley in Canada in 1926 in terms of 1,000 acres.*

Province	Estimated acreage in Charlottetown	O.A.C. 21	Duckbill	Chinese	Hannchen	Trebi	Manchurian 0.50	Total in Province[a]
Prince Edward Island..........	3	..	.	.	..	.	..	6
Nova Scotia.................	2	.		..	..	..	..	7
New Brunswick..............	2	1	..	..		.	..	6
Quebec......................	5	75	.	..	.	.	..	135
Ontario.....................	2	400	.	2	..	..	..	442
Manitoba	..	700	.	1		..	2	1,166
Saskatchewan................	..	400	1	.	200	5	..	744
Alberta	.	350	..	.	10	25	..	419
British Columbia.............	..	2	..	..	.		..	7
Total.......................	14	1,928	1	3	210	30	2	2,932

[a]From Monthly Bulletin, Agricultural Statistics, Ottawa, Jan. 1926.

average increase in yield the Canadian wheat growers are producing annually something like 80 million bushels of wheat more than they would were they still growing Red Fife.

In addition to Marquis, other improved forms of spring wheat have been produced by Canadian plant breeders, but none of them is grown on a very considerable area as yet. Two of the more promising recent productions, namely, Ruby and Huron, are each grown on an area that is estimated at 21,000 acres.

OATS

The total oat acreage and the estimated acreage of several varieties in Canada at present are shown in Table 8. By comparing the last row of numbers in the table it is seen that Banner or selections from it occupy by far the greater portion of the area in oats. Out of a total of 14½ million acres, about 9 million are seeded to Banner or selections from it, 2 million to Victory, and 1 million to O A. C. 72.

The following quotation from a recent letter by Mr. Newman to the writer is of interest. He says, "In the case of oats, there were many varieties other than those mentioned on the list (Table 8) grown twenty or thirty years ago. Banner is probably one of the oldest. The Banner that is now largely grown has been improved greatly by selection Victory, which was produced at Svalof, is rapidly gaining ground but taking Canada as a whole, the improved strains of Banner still occupy much the more important place."

There are no very trustworthy data which indicate the magnitude of the increased yields of oats that have been realized in Canada by the introduction of improved forms, but the readiness with which they have been accepted by the farmer is in itself evidence that the new forms are better than those they supplanted.

BARLEY

The production of barley in Canada is small compared with the production of wheat or oats. The total barley acreage and estimated acreage of several varieties are shown in Table 9 It will be observed that most of the barley is grown in the western provinces and that the estimated acreage of O. A. C. 21 is approximately 2 million, or two-thirds of the total barley acreage.

PRESENT TENDENCIES IN SMALL GRAIN BREEDING

What are the present tendencies in small grain breeding? In order to help formulate an answer to this question, cereal breeders and others working in closely allied fields were asked to name in order of importance the lines along which the improvement of small grain is sought at present.

TABLE 10—*Lines along which improvement of wheat is sought at present*

	Greater yield	Better quality	Stiffer straw	Winter hardiness	Rust resistance	Smut resistance	Non-shattering	Disease resistance	Resistance to Septoria	Earliness	Drought resistance
Rank as indicated by different persons	3	1	2								
	1	4	2	3				5			
	1	2		3							
	1	3		4	2						
	1	4	3					2			
			2			1					
		4	2	3	6	5				1	
	2	1			3						
	2	3							1		
		3	4	1							2
	4	3		2	1	5					
	5	4	3	1		2					
	1	3	5	2		4					
	5	4		1	2	3					
	5	3	4			1	2				
	1	2			3						
	1		2		3						
	1	4	2	5	3						
	6		1	2	4	5	3				
	1	2									
	2	5	3			1	4				
	3	4			1	2					
	1	6	4	2	3	5				7	
Total number of persons	20	20	14	12	11	11	3	2	1	2	1

TABLE II.—*Lines along which improvement of oats is sought at present.*

	Greater yield	Stiffer straw	Smut resistance	Rust resistance	Better quality	Winter hardiness	Disease resistance	Lighter color	Purify Kanota	Drought resistance	Earliness	Non-shattering
Rank as indicated by different persons	I	3	2									
	I	3		2								
	I	3			4		2					
					2				I			
		2								I		
	3	4	2	I								
	4	I	3	2								
	I	2		3	5						4	
	I	3	2									4
		3	2			I						
	I		3	2								
	I			3		2						
	I	2		3	5	4						
	2	I	4	3								
	I				2	3						
	I	3	2									
	2			I								
	I		2					4			3	
	I	2						3				
Total number of persons	16	13	9	9	5	4	I	2	I	I	2	I

TABLE 12.—*Lines along which improvement of barley is sought at present.*

	Stiffer straw	Greater yield	Smooth awns	Awnlessness	Better quality	Winter hardiness	Earliness	Drought resistance	Resistance to Helminthosporium	Disease resistance	Smut resistance
Rank as indicated by different persons		2	3				1				
		1	2	3							
	3	1			2						
	2	1	4	5						3	
	3		2			1					
	1							2			
	2		3						1		
	1		2								
	2	5	1				4				3
	2	1			3						
	2	1	3								
	3			2		1					
	1	2									
		1			2	3					
	2	1									
Total number of persons	12	10	8	3	3	3	2	1	1	1	1

The information obtained pertaining to wheat is shown in Table 10. The numbers in each horizontal row indicate the rank of the characters as designated by one person. Of 20 persons, 10 placed "greater yield" at the head of the list as the character most desired. The same number of persons (20) mentioned "better quality" as mentioned "greater yield," although the former was not considered quite so important. Some of the other important lines along which the improvement of wheat is being sought are stiffer straw, winter hardiness, rust resistance, and smut resistance.

The data in regard to the present aims in oats breeding are shown in Table 11. Here, as in the case of wheat, "higher yield" is considered of the most importance. "Stiffer straw" is second with "smut resistance" and "rust resistance" following. "Better quality" and "winter hardiness" were also mentioned by several persons.

The three outstanding problems in barley breeding as shown in Table 12 are "stiffer straw," "greater yield," and "smooth awns." Stiffer straw was placed at the head of the list of desirable characters by only three persons, but it was named more times than any other character.

TABLE 13.—*Average percentage reduction from full yield per acre from stated causes, as reported by crop correspondents, 1909–1924.*

Crop	Deficient moisture	Excessive moisture	Frost freeze or winter kill	Total climatic	Plant diseases	Insect pests	Total
Wheat.........	11.78	2.44	3.96	22.12	3.81	2.62	29.39
Oats...........	12.54	2.99	0.92	20.34	2.33	1.12	24.69
Barley.........	16.10	1.79	0.73	23.80	2.05	1.09	27.97

In considering the present tendencies in small grain breeding, it is interesting to note what "crop correspondents" have reported as some of the causes of reductions from full yield per acre of wheat, oats, and barley. The average percentages presented in Table 13 were computed from the percentage reduction in yield given for each year from 1909 to 1924, inclusive, in the *Yearbook* of the U. S. Department of Agriculture for 1925.

The estimated average percentage reduction in yield of wheat owing to adverse weather conditions is 22.12%. Deficient moisture, frost, freeze or winter killing, and excessive moisture are by far the most important elements contributing to this reduction. The development of winter hardiness and drought resistance in wheat should cut down somewhat the losses resulting from adverse weather, but this will probably always remain the most important non-controllable factor in reducing yield. Outside of climatic conditions, plant diseases and insect pests are the two most important causes of reduced yields. The former may be largely controlled and the latter may be controlled to some extent by cereal breeding. The data for oats and barley are similar to those for wheat, except that the latter show considerably more reduction in yield because of "frost, freeze, or winter killing" than do oats and barley. Barley shows the greatest loss due to "deficient moisture," no doubt owing in part, to the fact that this crop is grown extensively in the semi-arid regions.

DISCUSSION AND CONCLUSION

It may be desirable to return again to the question which is the title of this paper, "What has been accomplished by breeding small grains?" I believe the data presented show conclusively, first, that there is a considerable part of the small grain area in the United States and Canada seeded to recently improved varieties and, second, that an appreciable increase in yield has been produced in certain regions during the last two decades by the dissemination of improved varieties.

In this paper most emphasis has been placed on the increased yields which have resulted from the introduction of new and improved varieties because this, in the last analysis, is the most important character, yet many other characters are only a little less important than high yield. In fact many of them may limit yield. I refer to such characters as strength of straw, winter hardiness, and ability to resist the attacks of certain diseases and insects. Definite contributions to our knowledge of inheritance of these characters have been made. We not only know that these characters are heritable but in some cases, as for example resistance to rust and to smut, the manner of inheritance has been worked out in considerable detail. Moreover, new varieties have been discovered or synthesized which possess a high degree of resistance to these diseases. The progress that has been made in breeding small grains for resistance to certain diseases gives us grounds for hoping that eventually we shall have high yielding varieties for particular regions which are resistant to all the most injurious diseases in those regions. To the writer, this line of endeavor seems at the same time one of the most attractive and one of the most promising in cereal breeding.

The importance of strength of straw in small grains is so obvious that comment is hardly necessary. Several new forms have been discovered or produced which possess straw of a desirable stiffness, but there are still many varieties whose usefulness is limited because of a tendency to lodge.

Winter hardiness in oats, barley, and rye is of importance in certain regions, but winter hardiness in wheat is of more general interest. The annual losses owing to winter killing in wheat are much greater than in the other small grains. As a result of breeding, the winter wheat belt of several years ago has been broadened to the north and also there are available for the winter wheat belt generally relatively hardy forms that survive the occasional severe winter which kills less hardy varieties.

Quality of seed, like winter hardiness, is most sought in wheat. Our knowledge concerning the inheritance of this important character we owe to the cereal breeder. It is only necessary to mention one outstanding example of improved quality—the Marquis variety of spring wheat.

In addition to the important agronomic characters mentioned above there are several of more or less importance in certain regions, such as drought resistance, better color of grain, non-shattering, earliness, smooth awns in barley, etc. During recent years small grain breeders have added considerable information concerning the manner of inheritance of some of these characters and in some cases new forms have been produced which possess the desired character or characters. The Minnesota Station is distributing new varieties of barley which have smooth awns.

In a recent study, based largely on information contained in United States Department of Agriculture Bulletin 1074, Professor L. R. Waldron of the North Dakota Agricultural College arrived at the conclusion that 22.6% of the total wheat acreage in the United States is seeded to varieties that have been derived as a result of artificial hybridization. This excludes Fulcaster as of doubtful origin. Of the 22.6%, Marquis and Preston, both of which were produced in Canada, comprise 19.3%.

With regard to the future direction of cereal breeding the following quotation from page 165 of Professor E. M. East's book entitled "Mankind at the Crossroads" is pertinent. He says, "The prospects of increased yields and better quality of food products through straight selection of variant individuals is extremely low. The hopeful method of attack is by hybridization; yet even here it is doubtful whether a betterment greater than from ten to twenty percent can ever occur."

5. DISTRIBUTION AND MAINTENANCE OF IMPROVED VARIETIES OF SMALL GRAINS IN CANADA[1]

L. H. NEWMAN[2]

In Canada the systematic distribution and maintenance of improved seed stocks is regarded as one of the most important phases of the problem of "better crops." While the creation of superior new varieties obviously is of primary importance, yet if these varieties are not made available to and used extensively by those who grow crops, the years of patient effort expended by the plant breeder will count for little. Similarly, if proper attention is not given to the quality of the seed of these varieties, regarding the matter of purity and vital energy especially, their full value will not be realized.

The solution of these two problems of how best to distribute and to maintain the quality of superior varieties has been sought in various ways. One of the first methods followed in Canada was that of distributing free samples to farmers who might apply for them. This plan was followed chiefly by the Federal Department of Agriculture through the Experimental Farms system. In the province of Ontario the Agricultural College at Guelph has relied chiefly thus far, upon the *Experimental Union* as a means of accomplishing this work. While these methods are not without merit, yet the former method particularly is slow, more or less cumbersome, and open to suspicion as to the reliability of the yields reported. There also has been much doubt as to whether or not it has yielded returns commensurate with the money expended. As a result, the promiscuous distribution of free samples by the Federal Department was abandoned four years ago and in its place was introduced a plan of cooperative variety testing. Farmers who desire samples of certain varieties now are required to agree to conduct actual tests of at least four or five varieties for at least three years and according to a specified plan. This system is useful in indicating the various regions or districts within which certain varieties may be grown with greatest promise of success and to this extent contributes to a solution of the first of our two problems, *viz.*, that of bringing approved varieties into more general use.

Another method of facilitating the distribution of superior new varieties or strains is that of quietly multiplying the seed of such varieties until there is a sufficient quantity available to make it possible to put it on the market on a substantial scale. Individual farmers are thus able to obtain enough seed to try it out on an acreage basis. A very good illustration of how this method may operate was afforded in our experiences during the past spring in connection with the distribution of the new spring wheat variety, Garnet.

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[1] Paper read as a part of the symposium on "Procedure and Results of Small Grain Breeding" at the meeting of the Society held in Philadelphia, Pa., December 31, 1926.

[2] Agronomist, Central Experimental Farms, Ottawa, Canada.

This wheat had never been distributed and was practically unknown prior to the spring of 1926, by which time our Federal Experimental Farms, which originated and developed it, had multiplied it until there were available several thousand bushels. Thus, in 1925, we had fields of this wheat varying all the way from 5 to 70 acres on all of our Branch Farms in the Priarie Provinces. As these fields approached maturity they attracted a great deal of interest on account of the number of days they promised to mature ahead of such standard varieties as Marquis. It was also quite apparent, even to the casual observer, that the yields from these fields would be very satisfactory indeed. At our Branch Farm at Morden in Southern Manitoba, for example, 25 acres were harvested at least a week ahead of the first Marquis and produced an average yield of 41 bushels per acre. Going further west to our Branch Farm at Lethbridge in Southern Alberta, 60 acres yielded an average of over 38 bushels per acre and matured about seven days ahead of Marquis. This field, furthermore, was the only one in the district which was threshed ahead of the very bad weather which occurred in that section from the latter part of August to well into the Autumn.

Going north to our Station at Scott, Saskatchewan, in an entirely new type of country and where an early maturing wheat is usually an advantage providing it yields well enough, we find Garnet maturing about ten days ahead of Marquis and giving an average yield of 30.8 bushels per acre. The excellent results obtained from this early maturing, high yielding variety created an enormous interest with the result that very soon every paper in the country carried an article designed to draw attention to the value of this new contribution to Canadian agriculture Some of the statements made in the press were so extreme that we were obliged to make an official statement regarding the probable value of this variety. This statement, which of necessity had to present the actual facts of the case, served still further to stimulate interest, and very soon we became almost submerged in inquiries for seed. These inquiries were so numerous that a limit of 4 bushels per man was set. Even with so low a limit, the 7,000-odd bushels which we had for sale at $3.00 per bushel were very quickly absorbed by farmers, all of whom agreed to submit a report on the performance of Garnet in comparison with that of their main crop. Replies from these men, incidentally, will be summarized in a bulletin entitled "Garnet Wheat" which we are now preparing for publication.

It is quite safe to say that no variety in Canada ever became so widely distributed on so large a scale in so short a time. Starting with a few pounds in 1923, there were harvested in Canada in 1925 approximately 10,000 bushels, the greater portion of which was on our own farms.

Our experience in connection with Garnet would seem to indicate that this plan is a most effective one where one has a really valuable variety to offer. Farmers in western Canada, particularly, appreciate the opportunity of being able to buy enough seed of these new introductions to sow at least a few acres. Where a sufficient quantity of seed is available to provide visible demonstrations on this basis and over a wide area, it is possible to accumulate exceedingly valuable data on the relative performance of such varieties to supplement data already accumulated through the years of more exacting experimental work which necessarily must precede any such distribution.

MAINTAINING THE QUALITY AND PURITY OF DIFFERENT VARIETIES

To maintain effectively the standard and purity of improved varieties or strains once these come into general cultivation is a problem which requires organized effort of a high order. In the absence of any definite system, varieties are liable to become mixed or otherwise degraded and frequently even to lose their identity completely. This fact was considered so serious a matter in Canada several years ago that steps were taken by certain Canadian officials to organize an association of seed growers who would undertake to follow certain rules in connection with the propagation, handling, and merchandising of seed of approved varieties. This association, which was organized in 1904 under the name of the Canadian Seed Growers' Association, has come to occupy a place in Canadian agriculture of a degree of importance even greater than its most optimistic organizers had hoped for. It not only has proved a most effective means of maintaining the high standard of our improved varieties, but it has come to be regarded as one of the best media through which to bring improved strains and varieties into general cultivation. While it seems relatively easy to introduce a new variety which possesses some outstanding merit by means of the method employed in connection with the introduction of Garnet, yet, when the material to be placed on the market is simply a reselection or a "New Elite," it is necessary to resort to some more definite and precise plan such as that afforded by the above Association.

THE CANADIAN SEED GROWERS' ASSOCIATION

While the regulations covering the work of the above-named organization, as well as the course of procedure which is followed by its members, are given in detail in the annual reports of the Association, it seems desirable in connection with the present discussion to review briefly the more important features of the work.

A word first of all regarding the membership. This is composed of farmers who desire to produce high-class seed of approved varieties in order that they may profit by the demand that exists for this class of seed. Each grower is required to follow certain definite rules and to submit his growing crop to an official inspection before harvest. He must not grow more than one variety of any one kind on his farm, except where he desires to test a small quantity of some other kind. He must also exercise every precaution to prevent mechanical mixtures through threshing or cleaning machines or other agencies. After his seed is cleaned and ready for delivery he must submit it to a final inspection by an officer of the Federal Seed Branch, in order that it may be given its proper official grade and be duly tagged and sealed in standard sized sacks. The highest official seed grade in Canada is known as "Registered" seed and applies only to seed produced by members of the Association. The next highest grade is known as "Extra No. I."

The standard of purity for Registered seed and for Extra No. 1 seed is very high. Neither grade is permitted to contain any seed of those weeds which are listed as noxious under the Seeds Act and both must be practically free from seeds of other weeds classed as "non-noxious." Registered seed may contain not more than one other cultivated seed in 2 pounds of seed, while Extra No. 1 may contain not more than 10 other cultivated seeds per pound of seed.

As regards the standard of vitality, both of the above grades must germinate at least 95% in the case of wheat, flax, buckwheat, field peas, field beans, and sunflowers, and slightly lower in the case of the other cereals, as well as corn, vetches, and soybeans.

The problem of determining what varieties may be grown by members of the Association for registration has received a great deal of consideration. When the Association started its work, it was quite clear that the multiplicity of varieties which then existed was inimical to the most successful growing of crops. It was very difficult to obtain any considerable quantity of pure seed of any one variety.

There was also a good deal of uncertainty among farmers as to which varieties were the most desirable for their conditions. By limiting the varieties which may be grown for registration to those which are officially approved, the Association has rendered valuable service to the farming interests generally. To-day it is impossible to purchase Registered seed or Extra No. I seed of any variety which has not been very thoroughly investigated according to a definite plan laid down by the Association. This plan will not permit any new variety or strain to be accepted as eligible for registration unless:

"(a) It has been proven by methods here below designated to be superior, in one or more practical characters to sorts already accepted or recommended, and to be worthy of propagation over at least one distinct agricultural zone (as determined by soil, climatic, biologic or economic conditions).

"(b) It conforms to the standards of purity of type as set forth for the various crops (to be provided for by standing committees or otherwise).

"In determining whether or not a variety or strain shall be accepted for registration, the said variety or strain shall be carefully tested out in comparison with one or more standard varieties in the district for which it is being recommended, using approved agronomic practices of testing. The practices which are recommended by the Association are defined in detail. In presenting a variety for registration the procedure is as follows:

"(a) The breeder or introducer shall make application to his Provincial Seed Board to have the variety recommended for registration. He shall furnish the Board with full information regarding:

  "1. History of development, parentage, botanical and economic characters.

  "2. A full record of its performance in the comparative tests as outlined above.

  "3. A sample of seed sufficient to seed a fortieth acre plot.

"(b) If the Seed Board considers that the variety should be accepted for registration, it shall forward full information, as above, to the Secretary of the C. S. G. A.

"(c) The Secretary of the C. S. G. A. shall place the application before the Appeal Board, which will accept the variety if it has fulfilled all the requirements of registration.

"(d) The Secretary of the C. S. G. A. shall obtain from the originator or introducer for purposes of record at his office:

  "1. A sample of seed.

  "2. One or more representative plants showing the distinctive features of the variety.

The Appeal Board referred to above consists of three officials, namely, the Dominion Cerealist, Dominion Horticulturalist, and Dominion Agrostologist. This body, working under the regulations of the Association, makes the final decision as to whether or not a variety for which registration is sought has been tested according to the requirements of the Association and, if so, whether or not these tests indicate that it is entitled to recognition. No variety, no matter by whom produced, can be accepted for the production either of Registered seed or Extra No. I seed unless or until it has complied fully with the above requirements. This system provides a very effective means of preventing varieties which have nothing special to recommend them from being recognized under the two higher seed grades. Since those grades are the ones which are most profitable to handle, as a rule, varieties which cannot qualify for this recognition are not likely to get very far. The extent to which the Association has been able to limit the number of varieties in general circulation constitutes probably one of the most valuable features of its work.

Much of the success of the Association, especially in so far as concerns its handling of more or less contentious questions, may be attributed to the fact that its affairs are governed by a Board of Directors chosen from the different provinces. All technical matters upon which the board seeks advice are referred by it to a committee of plant breeders which includes a representative from each plant breeding institution in Canada. This committee is looked upon as the keystone of the Association, holding the whole fabric together. Plant breeders from the different provinces come together on a common ground, threshing out their difficulties and making definite recommendations which are agreed upon to be for the best interests of seed growing in Canada as a whole. The members of the committee themselves also profit by this arrangement which keeps them in close touch with the class of people for whom they are working. All provinces and plant breeding institutions in the Dominion are a party to the rules and regulations concerning seed growing which are adopted by the Association so that the interests of all are protected.

THE COMMERCIAL HANDLING OF HIGH GRADE SEED

In order to maintain the high standard of improved varieties throughout the country it is necessary to make it financially worth while for those concerned to produce pure seed of these varieties. This introduces the question of merchandizing and this phase of the problem is possibly the most intricate of all in some respects. Experience has shown it to be a relatively simple matter to arrange for the propagation of seed of certain varieties in almost any quantity desired, provided there be an assured outlet for the crop at a sufficiently attractive figure. The problem of handling and selling high grade seed is a business in itself, although inseparably linked with the problem of production. For many years the sale of registered seed was left almost entirely with the individual producer. If he happened to be a reasonably good business man, or if he happened to succeed in establishing a reputation as a producer of specially desirable seed, he usually succeeded fairly well in disposing of his crop at a fairly satisfactory price. However, since many of the best seed growers were not particularly keen business men, it often happened that their seed failed to find a market. This situation indicated the need for central selling agencies, central cleaning plants, and other cooperative means of handling the growers' product. As a result there are today in Canada a number of these local organizations which are handling the Registered and Extra No. I seed in carload lots as well as in smaller quantities. During the past three or four years considerable interest has also been taken by private concerns, such as local flour mills, in installing special seed-cleaning machinery for the cleaning of Registered seed produced in the district. The larger seed dealers in Canada are now regularly cataloguing these higher seed grades and are coming to constitute one of the best distributing agencies.

The more widely this seed becomes distributed the more general becomes the appreciation of its real worth. All this means not only a keener demand on the part of the average farmer to secure better seed than he has been growing but to take care of this seed when he gets it in order to prevent its degradation.

AN ALKALI FORAGE WEED—*BASSIA HYSSOPIFOLIA*[1]

P. B. Kennedy[2]

Early in 1921 a new soft-textured plant was found growing abundantly on strong alkali lands at Ingomar, Merced County, California. It was then in full flower (Fig. 1). A second collection was made in September of the same year when the plants were fully mature, brown, and uninviting.

Investigation proved that this plant had been collected by others near the U. S. Experiment Station, Fallon, Nevada; at Yakima Washington in 1919; and near Fresno, California. A note on the herbarium sheet bearing one of these samples states that it was growing to a height of from 2 to 5 feet in Bermuda grass sod. Since that time a number of collections have been made, indicating that it is quite abundant in Washington, Nevada, California, and probably other western states. It appears to flourish on lands too alkaline for most cultivated crops. Blake[3] gives a short account of the distribution and introduction of *Bassia hyssopifolia* (Pall) Kuntze. It is not mentioned by Bidwell and Wooton.[4]

Repeated reports that it was greedily eaten by stock and that it would grow readily on alkali lands induced the writer to consider its merits as a forage plant.

The plant is an annual, introduced from western Asia, but like many alien immigrants the "when and how of it" will probably never be known. In its native country it grows in saline sand or clay soils in the deserts, indicating that it would grow satisfactorily on American alkali soils without irrigation. Its wide distribution in a short time may be readily accounted for by the "seed," which is supplied with 5-hooked appendages (Fig. 2). If one brushes against the plants when they are mature, thousands of the tiny "seeds" adhere to one's clothing.

That Bassia has a high nutritive value may be gathered from the results of an analysis of plants in the flowering stage shown in Table 1.

The results of the analyses indicate that Bassia compares very favorably with alfalfa as a forage, if it is grazed while the plant is

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[1] Contribution from the Department of Agronomy, College of Agriculture. University of California, Berkeley, Calif. Received for publication April 18, 1927.

[2] Professor of Agronomy and Agrostologist in the Experiment Station.

[3] Blake, S. F. Two new western weeds. Science, 55:455. 1922.

[4] Bidwell, G. L., and Wooton, E. O. Saltbushes and their allies in the United States. U. S. D. A. Bul. 1345. 1925.

TABLE 1.—*Comparative analyses of Bassia hyssopifolia and of alfalfa.*[a]

	Moisture	Protein	Ash	Ether extract	Fibre	Nitrogen-free extract
	%	%	%	%	%	%
Bassia hyssopifolia	6.60	17.72	20.70	3.63	20.08	31.90
Bassia hyssopifolia (moisture free)	—	19.00	21.51	3.89	21.50	24.04
Alfalfa (moisture free) . . .	—	17.79	9.53	3.18	27.13	42.59

[a] Analyses made by B. A. Madson, Division of Agronomy, College of Agriculture, Davis, Calif.

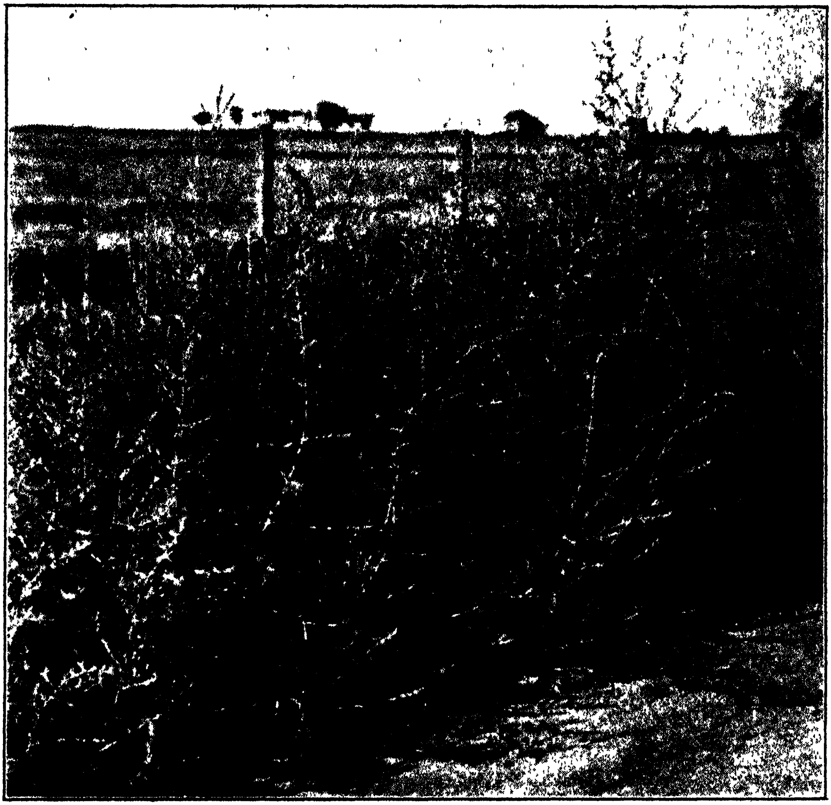

FIG. 1.—*Bassia hyssopifolia* along highway, Ingomar, Merced County, Calif., July 6, 1921.

in its younger stages or up to blossoming time before the stems begin to get hard and woody.

Since no adequate description of *Bassia hyssopifolia* is given in any of the literature available to most botanists and agronomists, the following is presented:

Annual, 30 to 120 cm tall, erect, more or less divaricately branched and ascending. Stems whitish, the entire plant covered by a minute pubescence. Foliage gray-green when young and yellowish-gray towards maturity. Leaves small 1 cm or less (in young plants larger), nearly sessile, numerous, linear-lanceolate, somewhat obtuse. Flowers gray-green in small bracted clustered spikes borne in the axils of the leaves, densely hirsute-pubescent. Calyx 5-lobed, covering the fruit, villous, each lobe developing from its centre dorsally towards maturity a horizontal hooked spiny appendage. Stamens 5 included, large. Utricle sub-orbicular slightly flattened, membranous. Seed ovoid, the membranous utricle more or less adherent, embryo large, curved.

A related species, *Bassia hirsuta* (L.) Aschers, also introduced from Europe, is reported as being very abundant on made-over land that is sometimes covered by high tides at South Boston, Massachusetts. Another well-known plant introduced from Europe and closely allied to Bassia is the summer cypress, red sage, or fireweed, *Kochia scoparia* (L.) Schrad. It is frequently used as an ornamental annual in gardens throughout the United States and other countries. Muschler in his "Flora of Egypt" states that it has been introduced into Egypt by the Howling Dervishes for making brooms. Individual plants if given ample space produce a symmetrical growth resembling miniature cypress trees. The foliage is a vivid green in summer turning a deep red in autumn. Seed is produced in abundance and it has escaped from cultivation to some extent. As pointed out by Bidwell and Wooton the summer cypress has possibilities as a range plant and the analysis of it given by them indicates that it has a high nutritive value. Hence it does not seem wise that measures should be taken for the destruction of this weed, as recommended by Blake. The alkali lands of the West are very much in need of palatable nutritious forage and as this is an annual it is not likely to become a menace to cultivated crops. In fact, it has frequently happened that annual alien immigrants of forage value such as "filaree," *Erodium cicutarium*, and the bur clovers have been of inestimable value to the stock industry. There is need for more aggressive palatable weeds that will help to crowd out the worthless species of *Centaurea* and the tarweeds and their kind all too numerous because there are not a sufficient number of nutritious aggressive weeds to subdue them.

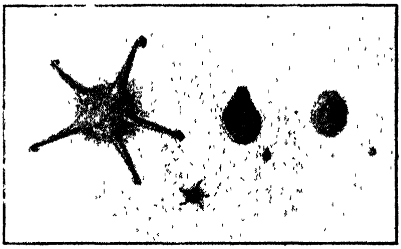

FIG 2.—Fruit, seed and urticle of *Bassia Hyssopifolia*, each X5 and natural size.

CONCENTRATED FERTILIZER EXPERIMENTS[1]

(Abstract)

J. J. Skinner[2]

The results of field experiments with air-derived nitrogen salts and with concentrated fertilizers are reported. Various nitrogen materials were used in experiments with cotton from 1921 to 1926 on 11 soil types. Each nitrogen salt employed served as the sole source of ammonia in a mixture containing 8% phosphoric acid, 6% ammonia, and 4% potash, which was applied at the rate of 900 pounds per acre. The average yield of seed cotton was as follows:

Sodium nitrate	1,362 pounds
Ammonium sulfate	1,335 pounds
Ammonium nitrate	1,325 pounds
Ammonium chloride	1,192 pounds
Ammonium phosphate	1,280 pounds
Urea	1,265 pounds

Experiments were made in 1925 with cotton in North Carolina and South Carolina; with sweet potatoes in North Carolina and with celery and lettuce in Florida; with two concentrated fertilizers made from (1) ammonium phosphate, potassium phosphate, potassium nitrate, and ammonium nitrate and (2) from ammonium phosphate, urea, and potassium sulfate. These mixtures were beneficial and produced as large yields as did fertilizers made from the commonly used fertilizer materials, but were non-drillable with commercial fertilizer distributers.

Experiments are reported which were made in 1926 with cotton and sweet potatoes, using five fertilizers made from concentrated materials. The fertilizers contained (1) ammonium phosphate, potassium ammonium phosphate, potassium nitrate, and ammonium nitrate; (2) ammonium phosphate, urea, and potassium sulfate; (3) ammonium phosphate, ammonium chloride, and potassium sulfate; (4) ammonium phosphate, ammonium sulfate, and potassium sulfate; and (5) treble superphosphate, urea, and potassium sulfate.

These fertilizers did not become hygroscopic or cake when a small amount of an organic filler, such as cottonseed meal, was included. Each mixture was drillable with certain types of fertilizer distributers.

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[1] Abstract of a paper read at a meeting of the Agronomy Section of the Southern Agricultural Workers' Association, held in Atlanta, Ga., February 3, 1927. Received for publication June 25, 1927.

[2] Biochemist, Soil Fertility Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.

Fertilizer formulas suitable to the crops grown were used. Approximately one-third of the quantity of each mixture supplied the same amount of plant food as a fertilizer of the same analysis made from the commonly used materials. The effect on crops of the concentrated fertilizers compares favorably to the commercial mixtures used.

RELATION OF LENGTH OF STAPLE TO YIELD AND VALUE PER ACRE OF COTTON IN THE SOUTHEASTERN STATES[1]

R. R. CHILDS[2]

All evidence points to fact that the percentage of short staple cottons is increasing and agronomists have found it difficult to induce growers to plant varieties of better staple. Data from experiment stations in North Carolina, South Carolina, Georgia, and Alabama throw some light on the situation.

TABLE 1.—*Average yield per acre of all varieties in each group for length of staple.*

	Staple length in inches				
	⅞ to $\frac{15}{16}$	1 to 1$\frac{1}{16}$	1⅛	1$\frac{3}{16}$	1¼
Yield per acre, pounds of lint.	463	400	368	343	311
Ratio yields	100	86.4	79.5	74.1	67.2
Value per acre[a]...	$104.18	$96.00	$95.68	$91.92	$87.08
Ratio value	100	92.1	91.8	88.2	83.5

[a]Values based on average Dec. 1 quotations, Memphis market, 1921 to 1926, inclusive.

Cotton averaging ⅞ to 15/16 inch in length of staple shows the highest yields and highest values per acre (Table 1). The decrease in yield as length of staple increases is 15% for first sixteenth above 1 inch and 6.5% for each sixteenth above this.

Even when one best variety in each group is considered, cottons with staples longer than 1 inch do not give as high yields as 15/16 inch staple (Table 2). Mexican 1$\frac{1}{16}$ inch in North Carolina and Acala 1$\frac{1}{16}$ inch staple in Alabama, at prices sold, are slightly more profitable and point to need for selection and adaptation of varieties to conditions prevailing in each state. The two cottons with a staple of less than ⅞ inch tested in North Carolina and Georgia gave a yield of only 90.5% as much as the 15/16 inch varieties.

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[1] Abstract of a paper read at a meeting of the Agronomy Section of the Southern Agricultural Workers' Association at the meeting held in Atlanta, Ga., February 2, 1927. Received for publication June 25, 1927.

[2] Profesor of Agronomy, Georgia State College of Agriculture, Athens, Ga.

TABLE 2.—*Average relative yield per acre of lint cotton for one best variety in each group.*

State	Staple length in inches						
	¾ to 13/16	⅞	15/16	1 to 1 1/16	1 ⅛	1 3/16	1 ¼
North Carolina.	92.0	87.0	100	97.0	77.0	81.0	73.0
South Carolina.	——	96.5	100	81.0	80.7	71.0	60.0
Georgia	89.1	96.4	100	81.4	80.8	78.0	70.0
Alabama	——	101.4	100	95.8	——	84.2	67.3
Average	90.5	95.3	100	88.8	79.5	78.5	67.6
		Relative values per acre					
North Carolina.	——	86.9	100	103.6	88.9	96.4	92.3
South Carolina.	——	96.5	100	86.4	93.2	85.0	75.5
Georgia	——	96.4	100	86.8	93.4	93.0	87.1
Alabama	——	101.3	100	102.2	——	100.3	85.2
Average	——	95.3	100	94.8	91 8	93.7	85.0

As contrasted with the above situation in the southeastern states, data from the Mississippi Delta Station is presented in Table 3.

Here staple cottons give a relatively high yield as compared with 15/16 inch cottons, and when one best variety in each group is selected the 1 1/16 and 1 3/16 inch cottons, both bred by the Delta Station, gave the highest yields and a much higher value per acre than other lengths of staple. Fertile soil, and high and uniform soil mositure are the principal differences in conditions in the Delta and the states farther east. The part that these two factors play in determining the profitableness of the longer staple cottons is a problem worthy of consideration.

TABLE 3.—*Relative yields and values per acre of different staples at the Mississippi Delta Station.*

	Staple length in inches						
	¾	⅞	15/16	1 to 1 1/16	1 ⅛	1 3/16	1 ¼
Relative yield, all varieties	95.5	95.8	100	90.2	87.4	94.4	66.2
Relative value, all varieties	93.0	92.2	100	103.2	106.3	123.9	95.3
Relative yield, one best variety	95.5	100.6	100	104.4	93.7	103.0	66.7
Relative value, one best variety	93.0	97.0	100	119.5	110.7	130.9	97.1

AGRONOMIC AFFAIRS

MINUTES OF THE 1927 CONFERENCE OF THE WESTERN SECTION OF THE AMERICAN SOCIETY OF AGRONOMY

The eleventh annual conference of the Western Section of the American Society of Agronomy was held at Moro, Oregon, from June 27 to 29. There was a total attendance of 53, nearly all of whom were experiment station and extension workers. The attendance by states was as follows: Oregon, 28; Washington, 9; Idaho, 7; Montana, 2; Utah, 2; California, 3; and U. S. Department of Agriculture, Washington, D.C., 2.

The conference was called to order at 9.00 a. m., June 27, by Mr. D. E. Stephens, Supt. Sherman County Branch Experiment Station, Moro, Oregon, who delivered the address of welcome as President of the Western Section of the American Society of Agronomy. The report of the Secretary of the 1926 meeting at Logan, Utah, was read by A. E. McLymonds, Supt. Experiment Station, Aberdeen, Idaho. Following this was the roll call when each one present gave his, name, position, and statement of lines of investigations. The following program of papers and discussions was presented.

SYMPOSIUM ON "CEREAL CROPS"

1. Registered Varieties of American Wheat: Their Class, Origin, and Acreage.
   J. A. Clark, U. S. Dept. of Agriculture, Washington, D. C.
   Discussion: D. E. Stephens.
2. A survey of Washington Wheats.
   E. G. Shafter, Agronomist, Washington State College.
   E. F. Gaines, Cerealist, Washington State College.
3. The Resistance of Winter Wheat Varieties to Low Temperature.
   D. D. Hill, Associate Agronomist, Oregon.
4. Growth Habit and Yield in Wheat as Influenced by Time of Seeding.
   B. B. Bayles, U. S. Dept. of Agriculture, Moccasin, Montana.
   Discussion. H. M. Wanser
5. Effect of Delayed Harvesting on Quality of Wheat.
   A. F Bracken, Supt. Experiment Station, Nephi, Utah.
   Discussion H. M. Wanser
6. Pure Line Theory Applied to Small Grains.
   E. N. Bressman, Associate Professor of Farm Crops, Oregon Agricultural College.
   Discussion: E. F. Gaines.
7. Relative Shattering of Oat Varieties at Moro, Oregon.
   T. R. Stanton, U. S. Dept. of Agriculture, Washington, D. C.

B. B. Bayles, U. S. Dept. of Agriculture, Moccasin, Montana. Paper read by Mr. Bayles.

8. Export Demand for Wheat Classes and Varieties.
   H. A. Martin, Kerr-Gifford Co., Portland, Oregon.
9. Sorghum Growth in Relation to Soil Temperature and Moisture Conditions.
   J. W. Gilmore, Professor of Agronomy, University of California.
10. Improvement of Coast Barley by Pure Line Selection.
    V. H. Florell, U. S. Dept. of Agriculture, Davis, California.
    Discussion: G. A. Wiebe, U. S. Dept. of Agriculture, Aberdeen, Idaho.
11. Effect of Seed Treatment on Germination and Subsequent Growth of Seeds.
    D. C. Smith, Fellow, Oregon Agricultural College.
12. Problems in Crop Standardization.
    G. R. Hyslop, Agronomist, Oregon Agricultural College.
    Discussion: L. Hegnaur, Extension Agronomist, Washington State College.

SYMPOSIUM ON "SOILS AND FERTILIZERS"

1. Factors affecting Changes in Organic Matter.
   H. F. Holtz, Assistant in Soil Physics, Washington State College.
   Discussion. W. V. Halverson and J. W. Gilmore
2. Some Relations of Moisture Usage to Drought Resistance in Wheat.
   H. M. Wanser, Supt. Experiment Station, Lind, Washington.
   Discussion: G. A. Mitchell, Asst. Supt. Exp. Station, Moro, Oregon.
3. Production of Artificial Manure by Fermentation.
   W. V. Halverson, Associate Professor of Bacteriology, Oregon Agricultural College.
   Discussion: H. F. Holtz.

SYMPOSIUM ON "FORAGE CROPS"

1. Adaptability of Red Clover to Western States.
   H. A. Schoth, U. S. Dept. of Agriculture, Corvallis, Oregon.
2. Alfalfa Investigations in Idaho.
   H. W. Hulburt, Agronomist, University of Idaho.
3. Irrigated Forage Crops.
   H. P. Singleton, Assistant in Crops, Washington Irrigation Branch Station, Prosser, Washington.

Discussion: A. E. McLymonds, Supt. Experiment Station, Aberdeen, Idaho.

SMUT PROBLEMS WITH REFEREENCE TO PACIFIC NORTHWEST EXPORT WHEAT

B. W. Whitlock, Bureau of Agricultural Economics, Charge of Pacific Coast Headquarters, Portland, Oregon.

A. F. Nelson, Bureau of Agr. Economics, Portland District Supervisor, Portland, Oregon.

SYMPOSIUM ON "CONDUCTING VARIETAL TRIALS WITH FIELD CROPS"

1. Cereals.
   J. A. Clark, U. S. Dept. of Agriculture, Washington, C. D.
   B. B. Bayles, U. S. Dept. of Agriculture, Moccasin, Montana.
2. Forage.
   H. A. Schoth, U. S. Dept. of Agriculture, Corvallis, Oregon.
   H. W. Hulbert, Agronomist, Idaho Experiment Station.

SYMPOSIUM ON "WEED CONTROL AND ERADICATION PROBLEMS"

1. Weed Control Work in Idaho.
   C. B. Ahlson, Seed Commissioner, Boise, Idaho.
2. Morning Glory Control.
   O. E. Lee, Fellow, Washington State College.
3. Morning Glory Control
   J. D. Remsberg, Assistant Agronomist, Idaho Experiment Station.
4. Weed Problems in California.
   J. W. Gilmore, Professor of Agronomy, University of California.

An especially interesting part of the program was the visit to Sherman County Branch Experiment Station which adjoins the city of Moro. The cultural practices developed and demonstrated at this station, with the development of improved cereal varieties has resulted in much material benefit to the grain growers of eastern Oregon.

The visitors were shown through the plats and nurseries by Supt. D. E. Stephens. Some of the outstanding projects under way are the improvement of the commercially grown Fortyfold, Turkey, Federation, and Hard Federation wheat. Bunt resistance in wheat and smut resistance in oats are a regular part of the cereal improvement program. Regal, a highly bunt resistant variety of the Turkey type recently developed, is about ready for distribution to competent growers.

The probable occurrence of the so-called German smut in the wheat fields of Oregon and Washington was indicated to the visitors when shown bunt-infected plants in the hitherto immune varieties Hussar and Martin. These varieties were treated before sowing with bunt inoculum obtained from a grain dealing firm in Portland, Oregon. Hussar and Martin have been immune to American strains of bunt and have been used widely by plant breeders in the development of bunt resistance in wheats.

That the more hardy trees including tree fruits can be grown successfully in this normally treeless region was demonstrated by plantings on the station grounds. A species of yellow pine obtained from the U. S. Forest Service was one of the new promising introductions.

At the business meeting the following resolution was passed:

Be it Resolved, That the Bureau of Agricultural Economics, U. S. Dept. of Agriculture, furnish more detailed information on forage crop estimates and on grades and prices of forage crop seeds and that an attempt be made to get quotations on seed prices to the 11 Western States at an earlier date.

The 1928 conference of western agronomists will be held at University Farm, Davis, California, and at the University of California at Berkeley. John W. Gilmore, Professor of Agronomy, University Farm, Davis, was elected President of the Western Section and V. H. Florell, Associate Agronomist, U. S. Dept. of Agriculture, Cooperative Cereal Investigations, at Davis, was elected Secretary. —V. H. FLORELL, *Secretary.*

NEWS ITEMS

H. K. WILSON, who completed graduate work for the Ph.D. degree in agronomy at the University of Illinois in June, was appointed on July 1 as Assistant Professor of Agronomy and Assistant Agronomist at the University of Minnesota Department of Agriculture and Experiment Station.

B. M. RALEIGH, a 1927 graduate from Kansas State Agricultural College, has been appointed as Instructor in the School of Agriculture at the University of Minnesota and Assistant Agronomist of the Experiment Station.

AN ERROR was made in the "News Item" in this JOURNAL for July concerning the appointment of Howard B. Sprague at the New Jersey College and Station. Dr. Sprague will be Head of the Department of Agronomy which is combined with the Soils Department (of which A. W. Blair is Head) to form the Division of Soils and Crops, of which Director J. G. Lipman is Chief.

W. H. METZGER completed graduate work for the master's degree in agronomy at Kansas State Agricultural College in June and has accepted a position in the Department of agronomy at the University of Arkansas.

ON JULY 1 the work of the former Departments of Soils and of Agronomy at the University of West Virginia was combined into a single department to be known as the Department of Agronomy.

HARRY R. GARDNER has resigned the position which he has held since July 1, 1926, as agent in the cooperative cereal disease investigations and experiments at Lafayette, Indiana, on June 30, to accept a position with the N. V. Potash Export My., at New York City. H. S. Jackson, who has been on sabbatic leave from Purdue University for graduate study at the University of Wisconsin, has been reappointed as agent in the cooperative investigations to fill the vacancy.

CORRECTION. The statement that M. A. McCall had completed the requirements for the Doctor's degree, which was made in this section of the JOURNAL for July, 1927, was an error.

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VIABILITY AND COMPOSITION OF "SEED" POTATOES AS AFFECTED BY CLIMATIC CONDITIONS AND BY VARIOUS OTHER FACTORS[1]

PHILIP H. WESSELS AND BURT L. HARTWELL[2]

INTRODUCTION

The first part of this paper deals with the factors which affect yield and the latter part particularly with the nitrogenous composition resulting from the influence of these factors.

The factors that influence the yields of potatoes may be regarded as operating in two ways, *viz.*, they may directly influence the size of the current crop or they may bring about a condition of the tubers that makes for vigorous production when used for "seed" the following season. The effects of the factors that directly affect the yield are apparent during the growth and harvesting of the crop; the effects exerted by the other factors are not in evidence until the following season. The value of a potato for seed purposes cannot be determined solely from its appearance. At present it is necessary to rely chiefly upon the production history of a potato to judge of its probable value for reproduction.

Certain localities have developed a reputation for producing seed potatoes of superior quality. It is a matter of quite general observation that potatoes which have been grown in more northern localities often produce considerably more than potatoes grown farther south when the two are planted under like conditions. This superiority of northern-grown seed has appeared so often on the plats of the Rhode Island Station, and in many cases has been so marked, that it was decided to attempt to find what factors in the growth of the potato were responsible for this increased vigor.

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[1] Contribution No. 346 of the Rhode Island Agricultural Experiment Station, Kingston, R. I. Received for publication April 27, 1927.

[2] Formerly Associate Chemist, and Director and Agronomist, respectively.

If the home production of good, vigorous seed potatoes could be brought about by varying the methods of growing the crop, much good might result to the grower. The introduction of diseases is facilitated by the use of imported seed potatoes. The history of the introduction of plant diseases, and the quarantine measures that are adopted to guard against this possibility, are ample evidence of this danger. Also, if the potatoes must be shipped in, there are delays and uncertainties of securing seed when wanted, the danger of damage in transit, the injuries that result from the increased amount of handling, and also the impossibility of being able to practice selection. Much has been done to improve plants through selection, but the grower who must depend upon some one else to supply him with seed potatoes must also, of necessity, depend upon some one else to do the selecting

NORTHERN VERSUS HOME-GROWN SEED

In an early bulletin of the Rhode Island Station (No. 36) some results of comparisons between the yielding power of home-grown and northern-grown potatoes were given which showed that northern-grown seed gave greater total yields and also a higher percentage of marketable tubers with 9 out of 14 trial varieties, but, on the other hand, the home-grown seed gave larger returns with 5 of the varieties. Additional information has been secured since that time which confirms these earlier findings, showing that while northern-grown seed is usually better than home-grown seed under Rhode Island conditions it is not invariably so. During the course of these experiments, 123 comparisons of northern- and home-grown potatoes were made.

Compared with the yields from northern-grown seed, the total yields per acre ran all the way from a loss of 157 bushels to a gain of 68 bushels through the use of home-grown seed. The use of home-grown seed resulted in an average loss of 66 bushels per acre. In total yield, the home-grown seed, on an average, produced only 76% as much as did the northern-grown seed. The yield of marketable tubers from the home-grown seed was 74% of that produced by the northern-grown seed. This decrease was in spite of attempts in many cases to maintain yields by tuber-unit selection.

As might be expected, the results obtained depended upon the varieties used. Eleven varieties were included in these tests. The Norcross, which was used in most of this work, gave, as an average of 45 trials, a yield of 184 bushels of marketable potatoes from home-grown seed as compared with a yield of 260 bushels from northern-grown stock. In spite of annual tuber-unit selection in Rhode

Island, the higher-producing units yielded in bushels per acre, 368 in 1913, 192 in 1914, and 117 in 1915, in which year new northern-grown seed yielded 269 bushels. Nineteen trials with the Green Mountain variety gave an average yield of 236 bushels of potatotes from home-grown seed as contrasted with a yield of 281 bushels produced by the northern-grown seed. Twenty-one comparisons of home-grown and northern-grown Irish Cobbler potatoes showed an average yield of 219 bushels of marketable potatoes from the former and 234 bushels from the latter. In general, it appears that the early varieties of potatoes are less adversely affected by our conditions than are the late varieties.

This falling off in yield, or decline in vigor, is variously spoken of as "running-out" or "degeneration," and has been the subject of much discussion in the literature on potatoes. Some writers hold that the potato is liable to this degeneration because of the manner in which it is propagated. The tuber is really only a thickened stem, and the theory is that all plants propagated asexually tend to "run-out." The fact that varieties come and go, and that few varieties of potatoes survive more than 40 years is pointed out as evidence confirming this. On the other hand, varieties of plants that are habitually propagated from seed also show this same tendency to disappear from cultivation, which may mean that they, too, are subject to deterioration or may merely be evidence that varieties disappear from cultivation not from degeneration but because better varieties have been developed which have displaced them.

The degeneration discussed in this paper is not concerned with the running-out of varieties themselves. It may be that these varieties are degenerating, but the records of yields obtained from good seed show no evidence to that effect. The yields vary with what may be termed good or poor seasons so that only the results of a series of years would furnish reliable evidence on this point.

Apparently, degeneration exhibits different characteristics in different localities. Certain types of degeneration may result from improper handling in storage or may be brought about by unfavorable growing conditions. A correlation between depth of eyes and degeneration has been suggested—shallow eyes being an indication of a tendency to degenerate—but, based on tuber appearances alone, no way has been found to separate vigorous from degenerate seed. Foliage characteristics seem to be the most reliable indicators of degenerate tendencies. As exhibited on the plats of the Rhode Island Station, the first and most striking difference that characterized degenerate home-grown seed was the irregularity of the stand. While the rows planted with good, northern-grown seed showed a remarkable uniformity of growth, adjacent rows planted with home-grown seed contained plants varying in size all the way from very dwarf to normal, vigorous plants.

CULTURE METHODS

In making the following comparisons careful attention was given to having the conditions as uniform as possible. The potatoes under comparison were usually planted in adjacent rows upon the plats, and the duplicate rows so arranged as to make the conditions the same for both lots. The soil, Merrimac silt loam, is fairly uniform on all the plats and, as the direct comparisons were confined to the potatoes grown in a single plat, it is probable that variations in soil had little, if anything, to do with the results obtained. The fertilizer applied to any given plat was, of course, distributed as uniformly as possible over the entire plat and the amounts used were such as were estimated to be sufficient for the crops that might have been produced, thus eliminating the fertilizer as a factor in securing these results.

The relative ability of good seed to produce may not be shown when the conditions are such as to limit the crop to the amount that might be produced by poorer seed.

In all the plantings, furrows were opened by machine and the seed pieces distributed by hand. The rows were 3 feet apart and the pieces were usually spaced 15 inches apart in the row. In the earlier work the seed pieces were cut to about the same size regardless of the size of the potato, so the amount of seed used per acre was very nearly the same in each lot under comparison. Later, the pieces were cut so as to give approximately the same number of eyes per piece. Still later, the size of piece and number of eyes were made uniform by choosing potatoes of similar sizes for the comparisons, and making the number of pieces the same in each lot. For example, it required 155 pieces to plant a row in most of the plats. To get this number there were taken, perhaps, 13 potatoes of one size, 17 potatoes of a smaller size, and 26 potatoes of a still smaller size. These were cut into four, three, and two pieces, respectively, and thus the weight of seed and number of eyes per row were made fairly uniform. The potatoes were divided by cutting along the axis of the potato from seed end to stem end. The time of planting, manner, time and number of cultivations and sprayings, and the date of harvest were the same throughout the plat, unless purposely varied, so the results must show the relative merits of the seed under the conditions of each test.

CUMULATIVE EFFECT OF SEED DEGENERATION

An essential part of work of this kind is a standard by which the extent of change can be measured. We were fortunate in securing the cooperation of the Maine Agricultural Experiment Station in supplying us with seed tubers of the same strain of Green Mountain potatoes grown in Maine year after year. Irish Cobbler seed was also furnished for several years. Assistance was also given in the study of the effect of storage upon the vigor of seed potatoes, some of the potatoes having been sent to us in the autumn and others sent in the spring, thus affording an opportunity to determine how much of the superiority of the northern-grown potatoes might be due to the storage conditions.

The previously mentioned results which showed the superiority of the northern-grown seed were based upon comparisons in which the home-grown seed had been grown only one season in Rhode Island. Had this seed been grown for a longer period in Rhode Island, the results would have been even more favorable to the use of northern-grown seed, as is brought out in Table 1.

TABLE 1.—*Rate of deterioration of seed potatoes grown in Rhode Island.*

Year of test	Variety	Yield in bushels per acre					
		Northern-grown	Grown in Rhode Island				
			1 year	2 years	3 years	4 years	5 years
1915	Norcross	258	246	155	—	—	—
1916	Norcross	139	40	41	38	—	—
1918	Norcross	381	388	327	—	—	—
1919	Norcross	37	60	98	66	—	—
Average		204	184	155	52	—	—
1916	Irish Cobbler	171	146	96	—	—	—
1917	Irish Cobbler	306	336	290	—	—	—
1918	Irish Cobbler	265	235	262	205	—	—
1919	Irish Cobbler	—	257	259	247	219	—
1920	Irish Cobbler	360	227	218	206	190	208
1921	Irish Cobbler	173	136	—	86	85	—
Average		255	223	225	186	—	—
1916	Green Mountain	126	32	18	—	—	—
1918	Green Mountain	305	309	288	—	—	—
1919	Green Mountain	76	33	29	32	—	—
1920	Green Mountain	281	133	99	91	—	—
Average		197	127	109	62	—	—
General Average		221	186	168	121	—	—

IMMATURE VERSUS MATURE SEED

The superiority of northern-grown seed has often been attributed to a lack of maturity in these potatoes. It is pointed out that in northern regions the potatoes are necessarily planted late in the spring, the growing season is short, and the vines are cut down by frost while still in a vigorously growing condition, consequently the potatoes do not have an opportunity to reach maturity.

Of the ways in which immature potatoes might be produced, only two appeared feasible under our conditions and both introduced factors other than the one of immaturity. The first method tried was that of harvesting potatoes at various dates throughout the growing season. There is no question about securing immature potatoes by this procedure, but it subjects the immature seed to a long period of storage at a time when conditions for farm storage are far from ideal. Some studies on the effects of storage upon the vigor of seed potatoes were therefore included in these trials. The results of a number of comparisons of the yields from home-grown potatoes harvested at different dates are given in Table 2. Usually the potatoes were dug at intervals of about three weeks, beginning at a time when the potatoes had reached a suitable size for seed purposes and continuing until maturity. Since the differences were not especially marked, only the results from the early and the late diggings are given.

TABLE 2.—*Average yields from early-dug and late-dug home-grown seed potatoes.*

Year of test	Variety	Number of comparisons	Yield in bushels per acre	
			Early-dug	Late-dug
1911	New Queen	8	128	115
1912	New Queen	2	206	128
Total		10	—	—
Average		—	144	117
1913	Clyde	2	153	297
1913	Norcross	5	201	162
1914	Norcross	4	303	264
1915	Norcross	1	293	304
1918	Norcross	6	382	371
1919	Norcross	2	107	60
Total		18	—	—
Average		—	279	251
1919	Irish Cobbler	9	257	225
1920	Green Mountain	1	103	91
1921	Green Mountain	3	234	159
Total		4	—	—
Average		—	201	142
Grand Total		43	—	—
General Average		—	230	206

The average of all the trials shows a gain of about 10% in total yield through the use of immature seed, but frequently this was due, in part, to the fact that the seed pieces in the earlier trials from the smaller, immature potatoes had more eyes. Direct comparisons with the northern-grown seed are not available, but the average gain from the use of northern-grown seed has been shown to be about a third.

The second method tried for securing immaturity was that of holding the seed until quite late in the spring or until the beginning of summer before planting. This method did not allow the plants time to mature before the tops were destroyed by frost, but it was open to the objection that the prolonged storage in the spring apparently robbed the potatoes of much of their vitality, though good results from this method are reported from New Jersey and other states farther south. Such seed is known as "second crop." Although several methods of storing the seed were tried, the results were not at all promising. Direct comparisons with northern-grown seed were made and the results are summarized in Table 3

TABLE 3.—*Comparison of average yields from immature seed potatoes secured by planting at a later date than usual, with those from regular, northern-grown seed.*

Year of test	Variety	Number of comparisons	Yield in bushels per acre Late-planted home-grown seed potatoes	Yield in bushels per acre Northern-grown seed potatoes
1915	Norcross	7	174	269
1916	Norcross	3	21	139
1918	Norcross	3	298	363
1919	Norcross	1	32	72
Total		14	—	—
Average		—	158	247
1915	Green Mountain	1	195	358
1921	Green Mountain	1	106	309
Total		2	—	—
Average		—	151	334
1915	Irish Cobbler	4	127	289
Grand Total		20	—	—
General Average		—	151	261

Since in these trials the immature seed was subjected to long periods of storage, attempts were made to find out to what extent the yields may have been influenced by this factor.

Potatoes were received in the fall from the Maine Experiment Station. These were divided into two portions, one of which was stored in the regular potato cellar and the other placed in a warm cellar. In the spring a second portion of this same lot of potatoes was sent down from Maine. The potatoes stored under these different conditions were planted side by side in one of the plats, attention having been given to making all other conditions as uniform as possible. The potatoes that had been stored in the warm cellar and planted in 1916 had sprouted considerably, which perhaps accounts for the increased yield in this case. As 1919 was a year in which late blight was very prevalent, the yields were much reduced. The results are shown in Table 4.

TABLE 4.—*Effect of storage upon yields.*

Source of seed	Yield in bushels per acre 1916	1917	1919
Seed stored in Maine	126	295	86
Seed stored in Rhode Island, root cellar	107	304	85
Seed stored in Rhode Island, warm cellar	166	281	—

EFFECT OF LEAVING POTATOES IN GROUND AFTER GROWTH HAD BEEN TERMINATED

When some of the immature potatoes were dug early in the season, the vines were removed from an equal number of hills and the potatoes left in the ground undisturbed until the time of the regular harvest. The early-dug potatoes were placed in a cool cellar or in cold storage until time for planting the following year. The average of all the trials during four years shows a yield of 207 bushels from seed placed in a cool cellar and a yield of 205 bushels from the seed that had been left in the ground after the tops had been removed to prevent further growth.

Three trials were made to determine the effect of cold storage upon the yielding power of seed potatoes. In two of these trials there was a very slight gain in favor of the seed that had been placed in cold storage. In the third attempt the yield from the potatoes placed in cold storage indicated that these potatoes had been injured.

EFFECT OF BURYING SEED POTATOES IN A PIT

The yields from late-planted potatoes have always been small, and the seed secured in this way has not given as good yields as has the immature seed that was secured by planting at the usual time and harvesting early. It was thought that this might be due to the difficulty of holding the potatoes in good condition so late in the spring, so a trial was made of the possibilities of burying the potatoes in a pit. Some home-grown potatoes were divided into four uniform lots, one of which was stored in the root cellar and the other three lots buried in a pit about 5 feet deep. Some hemlock boughs were placed under and over these potatoes and the dirt replaced. One lot in the pit had been coated with a thin paste of freshly slaked lime which was allowed to harden, one lot had been covered with a similar coating of plaster of paris, and the third lot had not been treated. When the pit was opened the following June, all the potatoes appeared to be in excellent condition. The coated potatoes showed no signs of sprouts, but the uncoated potatoes had just begun to sprout. The potatoes stored in the cellar had sprouts 1 to 2 inches long, nearly all of which were lost in handling. The yields obtained from this late-planted seed in 1920 and the results of using this crop as seed in 1921 are shown in Table 5. The yield from northern-grown seed of the 1920 crop is inserted for comparison.

The results of these trials indicate that the superiority of northern-grown seed is not due in any large degree to storage conditions.

TABLE 5.—*Effect of various treatments upon the value of the seed produced by late-planted potatoes.*

Source of seed and treatment		Yield in bushels per acre
1920		
1. Maine, 1918, lime-coated	buried in 1919 and planted late in 1920	83
2. Maine, 1918, plaster-coated		72
3. Maine, 1918, not coated		75
4. Maine, 1918, not coated, not buried, planted late		68
5. Maine, 1919, not coated, not buried, planted late		151
1921		
Seed from 1, planted usual time		107
Seed from 2, planted usual time		122
Seed from 3, planted usual time		113
Seed from 4, planted usual time		146
Seed from 5, planted usual time		87
Maine, 1920 seed, planted usual time		309

INFLUENCE OF THE NUMBER OF STALKS

Since the amount of seed used has a decided influence upon the yield, special attention was given to this point in all the later comparisons. In the earlier work the seed was cut as usual into pieces of about the same size and thus about the same number of bushels per acre was used in all those tests. It was apparent, however, that in some of those tests the numbers of stalks per hill were by no means uniform. This was especially noticeable in the various trials with immature seed, so an attempt was made to find out how this factor of thicker planting affected the yields. In Table 6 are given the results of using pieces cut to approximately equal weights but having varying numbers of eyes per piece, and also a comparison in which the size of piece was varied while the number of eyes per piece remained constant. A careful count of a large number of potatoes showed that the number of eyes on a potato of a given variety was about the same regardless of the size of the potato, there being as much variation among potatoes of the same size as among potatoes of different sizes. It will be seen that the number of stalks per hill was greatest where the number of eyes was greatest, that is, where equal-sized pieces were cut from both the larger and smaller potatoes. When the size of the piece was varied so as to have approximately the same number of eyes on each piece, the number of stalks per piece was not so greatly different in the different lots. The table also brings out the effect of the greater number of stalks per hill in increasing the yield.

TABLE 6.—*Influence of varying the size of piece and number of eyes per piece of seed potatoes.*

	Effect of varying the size of the seed piece			Effect of varying the number of eyes per seed piece		
Source of seed	Weight of seed piece in ounces	Number of stalks per piece	Yield in bushels per acre	Weight of seed piece in ounces	Number of stalks per piece	Yield in bushels per acre
Immature, small potatoes	1.19	2.48	291	1.19	2.48	291
	1.21	2.41	315	1.21	2.41	315
More mature, larger potatoes	2.07	2.86	242	1.21	1.85	219
	2.12	2.84	315	1.21	1.79	266
Mature, still larger potatoes	2.35	2.34	266	1.21	1.51	233
	2.31	2.49	296	1.21	1.48	259

Since the factor of immaturity also entered into these trials, some experiments were carried out in which the only factor that varied was the size of the seed piece. The influence of a difference in the number of eyes per piece was eliminated by removing all but two eyes from each seed piece, and in order to make the comparison as close as possible, the large and the small piece were derived from the same potato. The potatoes were divided by two cuts in planes at right angles to each other, their line of intersection coinciding with the long axis of the potato. The smaller piece was therefore approximately one-fourth of the potato and the large piece about three times the size of the small piece. Two side eyes were left on each piece, the eyes about the seed end having been removed as it is almost impossible to distinguish the separate eyes where they are grouped so closely.

The large pieces were planted in one row and the small pieces from the same potatoes were planted in an adjacent row. When the stalks appeared, it was noticed that more stalks were produced by the large pieces. It was thought that this might indicate, in spite of our efforts, that more than two eyes had been left on these pieces, so an examination was made by digging 40 hills. Twenty hills planted with large pieces had 79 stalks, while 20 hills planted with small pieces had only 44 stalks. As these numbers stood in the same relation as the numbers secured from a count of all the stalks and as no seed piece was found with sprouts from more than two eyes, it was evident that the increased number of sprouts was due to the use of the larger pieces. It was also found that, using the same sized pieces, the number of stalks produced depended upon the variety of potato used. The Green Mountain variety produced nearly 50% more stalks than did the Norcross under the conditions of these trials. That more stalks per eye should be produced from the larger pieces is not surprising, for the potato eye is really a cluster of buds and the increased amount of food available might well cause more of these buds to start.

Another thing that was brought out in these trials was the evidence of competition between hills when spaced 15 inches apart in the row. Where the large and small pieces were planted alternately in the same row, the yield from the large pieces was almost double that from the small pieces; but when the large pieces were planted in one row and the small pieces in an adjacent row, the large pieces produced only 25 to 30% more than the small pieces.

The results of using large and small seed pieces with two eyes in each are given in Table 7. This shows the influence of the size of the piece upon the production of stalks and upon the yields of large and small potatoes. In one trial the stalks were thinned to the same number as produced by the smaller pieces. The results indicate that the increased yield from the large pieces is due to the thicker planting, that is, the greater number of stalks per acre.

TABLE 7.—*Effect of size of seed pieces with two eyes on each.*

Variety	Weight of seed piece in ounces	Number of stalks per piece	Number of potatoes per piece		Yield in bushels per acre		
			Large	Small	Large	Small	Total
Norcross	1.24	2.16	5.94	1.81	303	23	326
Norcross. . .	3.30	3.67	7.48	4.11	340	56	396
Norcross	1.24	2.06	5.81	2.10	308	31	339
Norcross . . .	2.84	3.42	7.74	3.48	343	44	387
Green Mountain	1.32	3.05	—	—	304	14	318
Green Mountain	5.94	6.72	—	—	350	30	380
Green Mountain	1.50	3.38	—	—	269	24	293
Green Mountain	4.85	5.86	—	—	250[a]	18[a]	268[a]

[a] Stalks thinned to 3.38 per hill.

As these various trials had shown that both the number of eyes per seed piece and the size of the seed piece have an effect upon the yield, it was decided to use potatoes of as nearly as possible the same sizes in all the later tests, as explained previously. The pieces from the variously sized potatoes were segregated and, since the weight of the seed piece was about the same in each lot, an opportunity was afforded of noting the influence of increasing the number of eyes and of comparing the merits of seed pieces of the same size taken from large and small potatoes. (See Table 8.)

The weight of the seed piece was fairly uniform in any given comparison, except where the whole potatoes were used, these averaging slightly heavier than the cut pieces.

TABLE 8.—*Yields from equal-weight pieces from variously sized potatoes.*

Number of trials	Yield in bushels per acre from Potatoes cut into Quarters		Thirds		Halves		Whole potatoes	
	Large	Small	Large	Small	Large	Small	Large	Small
122	189	22	192	29	202	31	—	—
29	249	28	234	29	255	30	276	67

The number of stalks per hill increased with the number of eyes per seed piece. The average of 14 trials gave 1.98, 2.27, 2.56, and 3.32 stalks per hill from seed pieces consisting respectively of quarter, third, half, and whole potatoes.

RELATION OF SIZE TO MATURITY

There is the possibility that differences in maturity are not eliminated by thus using potatoes of equal sizes in making comparisons. A potato that weighs 4 ounces at the time when vines are mature may be really less mature than one that weighs 4 ounces very early in the season, but available evidence does not point to this conclusion. Careful counts of the number of tubers throughout the season showed that practically all the potatoes are "set" within a comparatively short time, the small potatoes found at harvest time simply having had a slow rate of development. Those which are small at the end of the season are of this relative size because of their failure to grow at a normal rate and not because they are of much more recent origin than the larger sizes.

MULCHING FOR THE PRODUCTION OF SEED TUBERS

Some investigators have reported good results from the use of a straw mulch in growing seed potatoes, so trials of this method were made. Northern-grown seed was used in the tests and this seed was divided into two uniform lots which were planted under like conditions, except that one lot was covered with rye straw to a depth of 6 to 8 inches when the plants were about 2 inches high while the other lot was given the customary cultivations. Care was taken in placing the mulch to see that the young plants were not covered. Both lots were given the same number of sprayings and were harvested on the same day. The seasons of 1916 and 1919 were very unfavorable for potatoes on the test plats, insects and diseases having been very abundant in both these years. (See Table 9.)

These results show that the use of the straw mulch tended to reduce the yields of potatoes, but that potatoes grown under a mulch were

TABLE 9.—*Effect of mulching upon yield of potatoes and their value as seed.*

Variety	Treatment	Yield in bushels per acre	Yield in bushels per acre when used as seed the following year
Norcross.......	Mulched, 1916	83	389
Norcross.......	Unmulched, 1916	139	320
Norcross.......	Mulched, 1917	310	416
Norcross.......	Uumulched, 1917	348	382
Green Mountain	Mulched, 1918	348	34
Green Mountain	Unmulched, 1918	381	44
Green Mountain	Mulched, 1919	54	231
Green Mountain	Unmulched, 1919	58	138

somewhat superior for use as seed. The average yields were 199 bushels when grown under a mulch and 232 bushels when grown without a mulch. Used as seed, the average yields were 268 bushels from the mulched potatoes as compared with 221 bushels from the potatoes grown without a straw mulch.

COMPOSITION OF SEED POTATOES

One purpose of this paper is to bring together some heretofore unpublished analyses of seed potatoes with brief reference to published work on the subject. The main incentive for the work was to ascertain if there were any definite relations between the chemical composition of seed potatoes and their viability, or their suitability for planting.

For many years, but subsequent to the beginning of this research, increasing emphasis has been given to "physiological or degeneration diseases" as being the influencing factors which cause deterioration of seed potatoes, therefore the chemical attack on the subject has been gradually withdrawn, and we shall not claim, in connection with the subject of viability, positive value for such results as we are in a position to report. They may prove useful, however, to anyone who may wish to consider them in connection with other analyses.

In Bulletin 153 of the Rhode Island Station (pages 110 to 115) it was shown that, although the substitution of sodium for potassium in the fertilizer materially decreased the growth of New Queen potatoes, the percentage of starch hydrolyzed by acid was not changed.[3] The percentage of nitrogen, however, was increased and the ash decreased by the substitution. The increase in the nitrogen was almost entirely in the portion soluble in saliva, which equalled about 70% of the total nitrogen, and was due to the omission of

[3] See Rhode Island Station Bulletin 165 for observations that growth inhibition in general is accompanied by an increase of starch in potato vines.

potassium rather than to the addition of sodium. There was not any difference in phosphorus percentage.

When planted on uniform land with plenty of fertilizer, the seed tubers which had been grown for one year without potash produced an average of 147 bushels an acre, whereas those which had been grown with potash averaged 113 bushels. Again, seed potatoes which had been grown for four consecutive years on plats receiving this same treatment produced, when used on the uniform soil, 81 bushels when the previous fertilizer had not contained potash and 64 bushels when the previous fertilizer had contained potash.

The seed potatoes were, in most instances, planted in about ounce pieces, consequently, the smaller the seed potatoes, the larger the number of stalks which arose from an ounce of "seed" and the greater the accompanying yield. In other words, any factor which reduces the size of seed tubers by this effect alone causes some increase when ounce pieces from smaller and larger potatoes are planted under favorable conditions, regardless of any other specific nutritional effect. The influence of certain of these factors is shown in Table 10.

TABLE 10.—*Effect on yield of potatoes when using ounce seed pieces from differently fertilized plats.*

Number of trials	Previous fertilization	Yield in bushels per acre
42	More potassium	109
	Less potassium	138
16	More nitrogen	91
	Less nitrogen	126
13	More phosphorus	138
	Less phosphorus	146
6	More lime	142
	Less lime	197

The fact that a higher percentage of nitrogen in the seed tubers grown with little potassium was correlated with subsequent increased yields may have been only a coincidence. Nevertheless, it was decided to determine the effect of certain factors on the composition of seed potatoes.

Because of the attention given in this paper to different nitrogenous portions of the potato, the one-time influence of field fertilization on the percentage of total nitrogen in the dry matter of the tubers is recorded below.

Fertilizer elements applied	None	2N P K	N P —	N -- K	2N 2P 2K	— P K	N 2P K	N P K
Nitrogen, %....	1.57	1.48	1.48	1.45	1.43	1.38	1.19	1.17
Relative yield..	50	100	62	67	95	46	94	73

Again, potatoes with relative yields of 100, 81, and 70, due to decreasing amounts of nitrogen, contained nitrogen in percentage of dry matter, respectively, as follows: 1.26, 1.04, and 1.11; and in another instance where omission of phosphorus reduced the yield a third, the percentage of nitrogen in dry matter was increased from 1.69 to 1.88, the phosphorus remaining practically unchanged.

METHODS OF SAMPLING

In taking portions of different potatoes for samples, all cuts were made along what may be considered as the long axis of the tuber. The first cut divided the potato into approximate halves. From these halves wedge-shaped slices were cut in such a way that their thin edges coincided with the long axis of the tuber. For samples used for the determination of soluble carbohydrates, these slices were about one-fifth of an inch at their thickest part. Considerable difficulty was found in determining the *dry matter* of large samples of potatoes, as too much heat resulted in forming hard, horny masses, and too little heat favored the growth of slime molds. A temperature of 65° to 75°C, with a large volume of dried air passing over the sample, gave a product that appeared uniform and which was easily powdered. The hard translucent masses that result when conditions are not right for rapid drying are no doubt derived from the starch, as this constitutes the bulk of the dry matter in the potato, and starch is readily hydrolyzed. Since the potato tuber is living tissue in which changes go on continually, it would have been better if these thin wedge-shaped slices had been dropped into boiling alcohol as is now recommended for plant tissues.

For total carbohydrate determinations, the slices were boiled, cooled, mashed to a pulp, and digested with ptyalin until no starch remained The solution thus obtained was made to a definite volume, and aliquots taken. These were "inverted" with HCl, cooled, neutralized, and the dextrose determined according to the Munson and Walker method.

For determinations of soluble carbohydrates, the slices were ground with sand in a glazed mortar and the pulp thrown onto a suction filter and washed with water. The sand and pulp were then returned to the mortar, leaving the filter paper undisturbed in the Buchner funnel. The grinding was continued until the pulp was thoroughly disintegrated. The sand and pulp were again transferred to the filter and washed with water until the volume was equal to a little less than 1 liter. After completing the volume to 1 liter, 6 aliquots of 50 cc each were taken for determinations of total and albuminoid nitrogen. The remaining 700 cc were concentrated to about 350 cc, hydrolyzed with HCl, cooled, neutralized, made to 500 cc, and sugar determined by the Munson and Walker method. The results were calculated as dextrose.

Total nitrogen was determined by the Kjeldahl method and albuminoid nitrogen through the use of Stutzer's reagent, the nonprotein nitrogen being the difference between these two determinations. It was thought that there might be some significance in the relationship of these forms of nitrogenous compounds, especially as they exist in the juice of the potato, so most of these determinations were made on the solutions that were obtained for determining the soluble carbohydrates.

COMPOSITION AS AFFECTED BY TIME OF DIGGING AND BY STORAGE

In Table 11, it may be seen that the fresh potatoes dug on July 26, August 21, and September 26, respectively, on the basis of dry matter increased in total and decreased in soluble carbohydrates. They also increased in the proportion of nonprotein to total soluble nitrogen. The general effect of storing until the next spring was to decrease the total and increase the soluble carbohydrates and to decrease the soluble nitrogen.

TABLE 11.—*Composition of Clyde potatoes, before and after winter storing, dug at different stages of maturity.*

	Date of digging		
Composition[a]	July 26	Aug. 26	Sept. 26
	%	%	%
Dry matter, before storage	21.93	23.60	23.39
Dry matter, after storage	20.60	23.34	24.16
Total carbohydrates, before storage	66.94	68.60	73.90
Total carbohydrates, after storage	61.54	61.85	57.42
Soluble carbohydrates, before storage	4.35	1.59	0.74
Soluble carbohydrates, after storage	3.76	3.00	3.10
Total nitrogen, before storage	1.42	1.38	1.50
Total nitrogen, after storage	—	—	—
Soluble nitrogen, before storage	1.28	1.11	1.19
Soluble nitrogen, after storage	0.85	0.66	0.69
Soluble nonprotein nitrogen, before storage	0.61	0.58	0.78
Soluble nonprotein nitrogen, after storage	0.48	0.45	0.50

[a] Carbohydrates and nitrogen computed on basis of dry matter.

"ASH SULFATE" INSTEAD OF DRY MATTER AS A BASIS FOR COMPARING COMPOSITION BEFORE AND AFTER STORAGE

It is realized that in comparing analyses of potatoes before and after storage the dry matter basis may not be the best one to use. The potato tuber is living tissue, and since part of its material is used up in the life processes during the period of storage, it would be better if some basis were chosen that does not increase or diminish during storage. It was thought that the amount of ash might serve as such a basis. The amount of ash present in the potato, however, is small and determinations of pure ash are not readily made. These objections might be overcome if the amount of ash could be increased, or the method of determining it could be simplified. The addition of H_2SO_4 gives an "ash" that can be burned to constant weight with very little trouble, and 50 to 60 grams of the fresh potato yields 0.7 to 0.8 gram of this ash sulfate. It is recognized that this procedure is useful only for comparisons of samples from the same lot of potatoes and that enough individual tubers must be taken to give representative samples. Consistent results were obtained when 20 tubers were used.

Slices were taken from each tuber, placed in a tared porcelain or silica dish, weighed, dried over a low flame, and ignited to whiteness after adding H_2SO_4. In some cases the addition of the acid was made to the fresh material and in others it was added after the drying had been carried so far that charring began. The final results were the same, but there was less tendency to spatter when the sample was charred before adding the acid. Different portions of the same fresh potatoes, in one lot, weighed 69.93, 64.90, and 62.75 grams and yielded, respectively, 1.22, 1.26, and 1.21% of ash sulfate; and, in another lot, weighed 56.91, 68.24, and 67.64 grams and yielded, respectively, 1.25, 1.17, and 1.19% of ash sulfate.

To illustrate the possibilities of this method, 2,432 grams of potatoes at harvest time weighed 2,301 grams the following spring and contained 1.373%, or 31.59 grams, of ash sulfate. This may be compared with 31.98 grams of ash sulfate in the sample as harvested based upon a duplicate sample which then contained 1.315% of ash sulfate. The sample at harvest contained 545.9 grams of dry matter and after storage 528.9 grams, a loss of 3%.

SOLUBLE NITROGEN AND ITS PROPORTION OF NONPROTEIN NITROGEN

These determinations have been found to exhibit some correlation with viability, and it would be desirable to learn whether there are any causal relations. In Table 12 may be found the effect particularly of soil treatment on this relation and also on the yield in 1920 on uniform soil where the yield of northern-grown seed was 260 bushels and where the samples were so matched as to contain equal-sized pieces and equal number of eyes. In the single instance of early digging given the total potato contained a larger rather than a smaller proportion of nonprotein nitrogen. There was also a larger proportion where less nitrogen was available to the plant. Differences

TABLE 12.—*Effect of the level of fertilizer nutrients on the composition of potatoes.*

Variety	Fertilizer nutrients	Yield in bushels per acre		On basis of dry matter of the potato							In the juice		
		In 1919	In 1920 from 1919 seed	Dry matter	Ash sulfate	Potash	Phos-phoric acid	Nitrogen	Non-protein nitrogen	Non-protein to total nitrogen	Total nitrogen	Non-protein nitrogen	Non-protein to total nitrogen
				%	%	%	%	%	%	%	%	%	%
Green Mountain	Less nitrogen	285	228	24.95	1.05	—	—	1.131	0.505	44.7	—	—	52.9[a]
	More nitrogen	348	180	23.85	0.83	—	—	1.508	0.573	38.0	—	—	—
Green Mountain	Less phosphorus	318	104	23.33	1.05	—	0.71	1.257	0.516	41.1	—	—	54.9[a]
	More phosphorus	296	125	22.28	0.99	—	0.69	1.347	0.573	42.5	—	—	56.1[a]
Green Mountain	Less potassium	322	264	23.18	0.91	1.88	—	1.656	0.726	43.8	—	—	48.9[a]
	More potassium	333	185	23.35	1.02	2.66	—	1.467	0.658	44.9	0.453	0.257	56.7[a]
Norcross (home-grown)	Less phosphorus	35	178	23.28	1.14	—	0.68	1.542	0.675	43.1	0.478	0.254	53.1[b]
	More phosphorus	54	146	23.36	1.10	—	0.70	1.709	0.710	41.5	0.583	0.290	49.7[c]
	Dug early	—	—	22.31	1.04	—	—	1.452	0.686	47.2	—	—	—

[a] These determinations were made after winter storage.

[b] After winter storage, 48.9%.

[c] After winter storage, 48.0%.

in phosphorus level had no clear influence on the proportion of nonprotein total nitrogen.

The omission of potassium has invariably increased the percentage of nitrogen and, when the deficiency has been marked, the proportion of nonprotein to protein nitrogen has increased, as may be seen again in Table 13 wherein are given analytical results with potatoes grown with the same amounts of nitrogen and phosphorus, but with different amounts of lime used with both sodium chloride and carbonate, with and without potassium chloride or carbonate.

TABLE 13.—*Effect of different levels of lime and potash on the nitrogen compounds of potato juice.*

	Total nitrogen in dry matter %	Nonprotein nitrogen in dry matter %	Nonprotein to total nitrogen %
Less-limed chlorides, no potassium....	1.87	——	——
Less-limed chlorides, potassium	1.52	——	——
More-limed carbonates, no potassium..	1.90	——	——
More-limed carbonates, potassium....	1.76	——	——
More-limed chlorides, no potassium...	2.31	1.44	62.3
More-limed chlorides, potassium.. .	1.72	0.90	52.3
Less-limed carbonates, no potassium. .	1.73	0.89	51.4
Less-limed carbonates, potassium.....	1.60	0.78	42.5

Similar differences are observable in Table 14 where the larger percentage of nitrogen and the higher proportion of nonprotein nitrogen accompany the northern-grown rather than the usually inferior home-grown seed.

TABLE 14.—*The nitrogen in the juice of northern- and home-grown seed potatoes in the spring.*

Year of test	Variety	Origin of seed	Yield in bushels per acre	Total nitrogen %	Nonprotein nitrogen %	Nonprotein to total nitrogen %
1909	Norcross	Northern	230	1.98	1.08	54.5
		Home-grown	235	1.63	0.80	49.1
1915	Green Mountain	Northern	349	1.76	1.04	59.2
		Home-grown	237	1.68	0.95	56.5
1916	Green Mountain	Northern	416	1.86	1.04	55.9
		Home-grown	121	1.65	0.87	52.7

SUMMARY

Especially the later varieties of potatoes grown at the Rhode Island Station are about a fourth less valuable for seed than those grown in northern New England. They progressively deteriorate even in spite of tuber-unit selection. The inferiority of the home-grown seed exhibited itself largely by a considerable admixture of inferior plants presumably affected by one or more of the so-called degeneration diseases.

Storage conditions are not important factors in connection with viability.

When smaller and larger seed potatoes were compared on the usual basis of about ounce pieces, conditions which had materially reduced the growth previously without affecting healthfulness, regardless of any other effect, resulted in seed which produced larger yields per acre, provided cultural conditions were satisfactory.

Too pronounced acid-soil conditions, a shortening of the growth period, and insufficiency of any one of the fertilizer nutrients are such growth-limiting factors which were observed.

When all but two "eyes" were removed from both partly developed and fully developed potatoes, the smaller potatoes were frequently not more productive. In fact, the larger potatoes or pieces led to a larger number of stalks from the two compound eyes, and somewhat larger production. When the stalks from the larger pieces were reduced to the number which arose from the smaller pieces, the yield was about the same in both cases.

Nevertheless, even when seed for comparison was matched so that both samples contained the same number of different sized potatoes cut the same, there sometimes occurred differences in viability due to fertilization.

Attention is called particularly to the tendency towards increased viability accompanying a scarcity of potassium, and to the larger percentage of nitrogen and greater proportion of nonprotein nitrogen in such seed. These same tendencies were exhibited by the superior, northern-grown seed when their analysis was compared strictly with that of home-grown seed.

In addition to the determination of nitrogenous constituents, carbohydrate variations were determined in potatoes harvested at different stages of growth and analyzed before and after winter storage.

Sulfated potato ash is suggested as an unchanging basis for comparison of analyses of potatoes before and after storage.

TIME AND RATE OF BLOOMING IN RICE[1]

H. H. LAUDE AND R. H. STANSEL[2]

A knowledge of the development of the inflorescence of a plant is necessary before hybridization can be undertaken with any reasonable degree of certainty. Thus, as a preliminary phase, a study of the panicle of rice (*Oryza sativa*) afforded information on the following points: (a) Time of day blooming occurs and rate of blooming during the different parts of this period, (b) length of the blooming period of the panicle, (c) length of time from full boot to first bloom, (d) order of blooming in the panicle, (e) arrangement and position of florets in the panicle, (f) length of time the flower remains open, and (g) influence of variety on rate of panicle development. This work was conducted on Substation No. 4 of the Texas Agricultural Experiment Station, at Beaumont, Texas, in 1916 and in 1919.

REVIEW OF LITERATURE

Akemine (1)[3] found that under normal conditions blooming in rice begins between 9:00 a. m. and noon and ends about 3:00 p. m. He also noted that the flower remains open from 1.5 to 2.5 hours and that light has no direct effect on blooming.

Knuth (4) reported that blooming appears to continue during the whole day and that the panicle begins to open at the tip.

Van der Stok (6) states that in Java the rice blossoms do not open before 6.00 a. m. or after 3:30 p. m., and that the greater number open between 10:00 a. m. and noon.

Jones (3), who worked in California, noted that over three-fourths of the rice flowers observed bloomed between 12:00 noon and 2:00 p. m., and that more flowers bloomed between 2.00 and 4:00 p. m. than between 10:00 a. m. and 12:00 noon. Varietal differences appeared to have some influence on the time of blooming.

Pope (5) states that blooming proceeds from the top of the rice panicle downward and from the free end of the panicle branch to its base.

Hector (2) found that in Lower Bengal during May and June blooming commences usually between 7:00 and 8:00 a. m. and continues until about 10:00 A. M., while in late October and early November blooming begins two hours later and continues until

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[1] Contribution from the Texas Agricultural Experiment Station, College Station, Texas. Received for publication May 2, 1927.

[2] Formerly Superintendent, Texas Substation No. 4, Beaumont, and Superintendent, Texas Substation No. 3, Angleton, respectively.

[3] Reference by number is to "Literature Cited," p. 787.

mid-day. Among varieties that bloom early in the season, the flowers seldom remain open longer than 0.5 hour, while in the case of late varieties they remain open from 1 to 1.5 hours. If the weather is wet and rainy at the time the flowers should normally open, they may not open at all, or if they do, they may not close again. Blooming usually takes place on the same day as that on which the spikelet emerges above the level of the leaf sheath, if this happens before mid-day, or at the latest, in the course of the forenoon of the following day. In about four days the whole panicle will ordinarily have bloomed.

MATERIAL AND METHODS

In 1916, 25 panicles of rice were studied throughout their entire blooming period during which observations were made on 5,479 florets. Five varieties were included. Numbers 1518 and 1589 grow rapidly, tiller abundantly, and produce high yields. Number 1589 grows somewhat taller than Number 1518 and produces a longer panicle. Number 1599 is a medium sized variety of the Japan type. It tillers freely, has small stems, medium sized panicles, and short, thick kernels. Numbers 1611 and 056 are of the Honduras type. They tiller sparingly, have large erect stems, long panicles, long kernels, and grow rather slowly.

In 1919, 20 panicles of the Early Prolific variety were studied during the first five days of their blooming period, observations being made on 2,423 florets. This variety tillers freely, grows to medium height, is a fairly rapid grower, has a medium length of panicle, and medium sized kernels.

The anthers of rice lie in a compact group parallel to the longitudinal axis of the floret. Before blooming they appear as a dense yellow spot within the glumes and may be observed by holding the floret between the observer and the light. After blooming, the glumes appear empty. Absence of the anthers from the glumes was considered evidence that blooming had occurred, except where the florets were open at the time of observation. To prevent counting a floret more than once, a dot of ink was placed on the glume of the florets that had bloomed.

Observations were made at intervals of one hour, and standard time was used in recording the data. At Beaumont, in 1916, this was about 20 minutes sooner than sun time. In 1919, the data were taken by "daylight-saving" time, but have been adjusted to make them comparable with the data for 1916.

By "full boot" is meant that stage of development at which the terminal floret on the panicle emerges from the sheath. The condition "full head" is reached when the basal node of the panicle emerges from the sheath. Since the lowest floret on the panicle is usually some distance above the basal node, the time required for all the florets to emerge is shorter than for the emergence of the entire panicle. The process of blooming is considered to begin when the glumes open and the record of the time of blooming as reported refers to the opening of the blossom.

EXPERIMENTAL DATA

TIME OF DAY RICE BLOOMS

There was no blooming before 8:00 a. m. and none after 4:00 p. m. in either 1916 or 1919, as shown by the hourly bloom counts given in Tables 1 and 2. The majority of the florets opened between the hours of 10:00 a. m. and 2:00 p. m., with the peak between 11:00 a. m. and 12:00 noon. On August 9, 1919, there was a very pronounced departure from the normal time of blooming, since no florets opened before noon of that day. This was apparently caused by rain which began at 8:00 a. m. and continued until 11:15 a. m.

TABLE 1.—*Hourly bloom count on 25 panicles during entire blooming period of 1916.*

Date	Number of blooms Hour							Total
	8–9	9–10	10–11	11–12	12–1	1–2	2–3	
Aug. 22				6	1			7
23		3	57	194	89	47		390
24	8	30	197	535	427	109		1,306
25		4	27	399	828	241	41	1,540
26	5	44	125	574	365	32		1,145
27		36	323	264	57	18		698
28		68	66	125	33			292
29		2	16	53	10	1		82
30		3	9	5				17
31								
Sept. 1			2					2
Total	13	190	822	2,155	1,810	488	41	5,479

TABLE 2.—*Hourly bloom count on 20 panicles during first five days of blooming period, 1919.*

Date	Number of blooms Hour								Total
	8–9	9–10	10–11	11–12	12–1	1–2	2–3	3–4	
Aug. 8		3	3	293	52	16			367
9					18	633	148	7	806
10	6	99	218	206	20	5			554
11			258	79	124	29	2		492
12		6	39	146	13				204
Total	6	108	518	724	227	683	150	7	2,423

TABLE 3.—*Daily bloom count on 25 panicles during entire blooming period, 1916.*

Selection No.	Panicle No.	Number of blooms											Total
		August										Sept.	
		22	23	24	25	26	27	28	29	30	31	1	
1518	1		15	67	86	31	30	1					230
	2		19	84	71	46	20	2	2				244
	3		8	57	45	34	24	10	3				181
	4		22	64	76	49	7						218
	5		9	50	56	40	32	12					199
	6		11	64	73	35	29	12	1				225
1589	1		26	64	59	58	24	24					255
	2	7	61	52	44	36	13						213
	3		33	61	56	42	6						198
	4		45	74	68	43	19						249
	5		18	74	78	72	27	4					273
	6		9	47	70	60	23						209
1599	1		34	22	64	42	27	34	4	2			229
	2		20	61	50	38	16	7					192
	3		19	27	44	34	18	9	3	1			155
	4		9	49	64	36	29	9					196
1611	1		12	60	69	43	22	9					215
	2		13	49	78	54	22	24	3				243
	3			54	17	50	52	30	11	2			216
056	1		4	39	52	25	20	7	2				149
	2		1	35	54	38	52	14	8				202
	3		2	31	56	51	47	15	7	5			214
	4			39	74	48	52	17	8				238
	5			41	61	66	36	27	16	6		2	255
	6			41	75	74	51	25	14	1			281
Total		7	390	1,306	1,540	1,145	698	292	82	17		2	5,479

LENGTH OF BLOOMING PERIOD

In 1916 the greatest number of florets in the 25 panicles studied opened on the fourth day after blooming began, as shown in Table 3. The panicles completed blooming in from five to nine days, the majority taking six or seven days. All the panicles produced the largest daily total of open florets on the second and third day after blooming had started, with the exception of one which had the greatest number on the first day.

TIME FROM FULL BOOT TO FIRST BLOOM

The 25 panicles under observation in 1916 reached full boot between 8:00 a. m. and 6:00 p. m. on August 22. The first panicle to emerge bloomed the same day, 20 panicles bloomed the following day, and the remaining 4 panicles bloomed on August 24. On the morning of August 8, 1919, 20 panicles were selected which had emerged from 1⅛ to 3⅞ inches, but which had not bloomed at the time of selection. All bloomed that day. It seems that blooming usually begins the first day after the panicle emerges, though frequently it begins the second day, The panicles which begin to emerge late in the afternoon or during the night may not begin blooming the following day.

ORDER OF BLOOMING IN THE PANICLE

A limited study indicates that the florets bloom in a fairly definite order, as indicated in Table 4. In primary branches the terminal floret usually blooms first and the fifth or sixth blooms second. However, this order is sometimes reversed. In the secondary branches, which bear from two to five or six florets, the terminal floret usually blooms first and the second floret is last or among the last to bloom. Since the total number of florets was not the same on all the branches studied, the numerical designation of the order of blooming given in Table 4 can be used only in a general way. It seems conclusive, however, that blooming begins either with the terminal floret or about midway down the branch, and then proceeds both ways from the latter point, progressing usually one or two florets upward before going downward. In nearly every case the second floret, along with some at the base of the branch, is the last to bloom.

TABLE 4.—*Order of blooming in the rice panicle, record for one day.*

Branch	Position of floret									
No.	Terminal	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
1	1		4	3	5	2				
2	1	8	7	3	4	2	6		5[a]	
3	1	7	5	4	3	2	8		6[a]	
4	3		2	5	1	4	6			
5	1	8	7	4	5	2	6[a]			3[a]
6	1	5	6	2	4	3				
7	1		6	4	3	2	7[a]			5[a]
8	2			4	3	1	5			
9	2			4	1	3				
10	1				2	3	4			
11	3			4	2	1				

[a] Terminal floret on a secondary branch.

ARRANGEMENT AND POSITION OF FLORETS IN PANICLE

The florets are arranged in a definite way as regards position in the panicle. It was found characteristically true that the two florets at the extremity of the branch have the same position with regard to direction, and that the florets that are attached below these alternate in direction. The basal floret of the uppermost secondary branch has the same direction as the lower floret that is attached singly, while the lowest florets on the remaining secondary branches alternate in direction.

It is evident that neither a secondary branch nor a floret may be missing or removed without breaking the systematic arrangement. Since the kernels are borne singly in the spikelet, the number in the panicle is almost definitely determined at the time the head is formed. In wheat or oats the development of the third kernel in the spikelet may be determined at any time prior to the end of the pollinating period, depending upon the available nutrition. This fact may have a practical bearing in that an improvement in environmental conditions, particularly nutritional factors, during the latter part of the growing season can result in an increased yield of rice only by increasing the size of the kernel and not the number of kernels.

LENGTH OF TIME THE FLOWER REMAINS OPEN

A few observations indicate considerable variation in the length of time rice flowers remain open. Data on seven florets in Table 5 show a range of from two-thirds hour to slightly over two hours, although four of them completed blooming within an hour. In the blooming data recorded hourly it was noted that many florets opened and closed within one hour.

TABLE 5.—*Length of time the rice floret remains open.*

Floret No.	Time of opening	Time of closing	Minutes open
1	12:22 p. m.	1:04 p. m.	42
2	12:20 p. m.	1:10 p. m.	50
3	12:44 p. m.	1:25 p. m.	41
4	9:45 a. m.	10:45 a. m.	51
5	10:25 a. m.	11:45 a. m.	80
6	2:20 p. m.	4.25 p. m.	125
7	2:20 p. m.	4:25 p. m.	125

TABLE 6.—*The influence of variety on the rate of panicle development in rice.*

Selection No.	Avergc number of hours from full boot to All florets out	Avergc number of hours from full boot to First bloom	Average number of hours from first to last bloom	Average number of florets appearing every 24 hours	Average length of panicle appearing every 24 hours, mm
1518	48.70	23.33	122.82	113.95	78.30
1589	57.44	22.58	144.45	98.03	88.30
1599	67.63	23.37	144.25	68.58	74.33
1611	75.25	30.25	136.70	71.68	74.32
056	85.11	26.09	146.94	64.16	66.80

The blooming process may be divided into three distinct periods, namely, the time required for the glumes to open, the time they remain open, and the time required to close. The first of these is short, usually between one and three minutes; while the last two are relatively long and require about the same amount of time.

INFLUENCE OF VARIETY ON RATE OF PANICLE DEVELOPMENT

There was considerable difference among the varieties studied in regard to the rate of development of the panicle, as shown in Table 6. The most rapid growing varieties, Number 1518 and Number 1589, required a shorter time between full boot and full head, had a larger number of florets, and a greater length of panicle appearing every 24 hours than did the other varieties under consideration.

SUMMARY

In a study of the inflorescence of rice grown on Substation No. 4 of the Texas Agricultural Experiment Station observations were made on 45 panicles, including 7,902 florets and representing six varieties or selections.

No blooming occurred before 8.00 a.m. and none after 4:00 p.m. The maximum number bloomed between 11:00 a.m. and 12:00 noon.

The majority of the rice panicles completed blooming in six or seven days, with the maximum number of florets opening on the second or third day after blooming started.

Blooming usually began the first day, although in many cases not until the second day after the condition of full boot was reached.

The terminal floret and one about midway down the branch bloomed first. Blooming then proceeded both ways from the latter point. The second floret, along with those at the bottom of the branch, was the last to bloom.

A systematic arrangement of the florets was noted in the main and secondary branches.

The blooming process required from less than one hour to two hours in the few cases where this point was observed.

The rate of panicle development differed among the varieties, being positively correlated with the rate of vegetative growth throughout the season.

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TEXTURE AND STRUCTURE OF SOILS AS INFLUENCED BY CHEMICAL AGENTS[1]

George J. Bouyoucos[2]

In a former paper[3] the results of an investigation on the granulation of soils were presented. It was shown that water played a most important rôle in the granulation of soils, but in a different manner from what is commonly believed.

In that investigation, it was observed, that when large pieces or blocks of dry soils were immersed in an excess of water, the soils tended to disintegrate or slake into their ultimate single particles or into compound particles, or crumble into small pieces. The rate at which this disintegration would take place, varied with the soils.

This observation presented a very interesting phenomenon, and the question arose, What effect would different chemical agents, such as salts, acids, and bases, and a difference in the concentration of these agents, have upon the disintegration or slaking of soils? It appeared that not only some interesting and important information and relationships might be established between the rate of slaking of soils and the nature and concentration of the reagent, but also it afforded a rather unique and excellent way of studying directly the effect of the chemical agents on the physical condition of the soils and consequently upon their texture and structure, upon flocculation, deflocculation and swelling of soil colloids, upon the rate at which the soils absorb the water, etc. It is the object of this paper, therefore, to present the results obtained in the study in question.

METHOD AND PROCEDURE

The method adopted and followed for studying the slaking of soils consisted of placing dry balls of soils into an excess of liquid and noting the rate or time required for complete slaking and also the texture and structure of the slaked material. Balls were used because they could be made to be quite uniform in size, texture, structure, density, etc., and thus give more uniform and comparable results between the different soils. They were prepared by working the soil first into a dough or plastic condition, and then a certain and uniform amount was taken and rolled between the palms of the hands into balls. After a certain amount of experience was acquired these balls could be made quite uniform in size and density. After drying, which always took place at room temperature, they were very hard. With the exception of one soil the balls did not crack in drying. Their surfaces were smooth and uniform. As they were dried in a heated laboratory, their moisture content was very low. Their size was about one-half inch in diameter.

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[1] Contribution from the Soils Section, Michigan Agricultural Experiment Station, East Lansing, Mich. Received for publication May 3, 1927.

[2] Research Professor in Soils.

[3] Bouyoucos, G. J. The influence of water on soil granulation. Soil Science, 18:103–109. 1924.

EXPERIMENTAL RESULTS

There were 15 different soils used in the study of slaking, namely, Michigan sandy loam, Michigan silt loam, Miami silt loam, Napanee silt loam, Osago silt loam, Memphis silt loam, Grundy silt loam, Brookston clay loam, Minnesota Carrington clay loam, Saginaw clay loam, Illinois red clay, Decatur clay, Pierre clay, Clyde clay, and California Yolo clay.

The slaking of all or part of these soils was studied in 11 different chemical reagents, namely, NaCl, KCl, $CaCl_2$, $NaNo_3$, NH_4NO_3 Na_2SO_4, CaH_4Po_4, HNO_3, HCl, KOH, and sugar. There were three or four different concentrations in all of these chemical reagents. For those chemicals which had a high solubility the concentrations consisted of 1 N, 3 N, 5 N, and 7 N solutions. Those which had a lower solubility permitted only a 5 N as the highest concentration. At these highest concentrations, the solution was completely or almost saturated in many of the reagents.

In the following tables are presented some of the most typical experimental results obtained. They show the time required for the balls of the different soils to slake or disintegrate completely in the various chemical reagents of different concentrations with water as a check. The figures are usually the average of three or four trials. As a general rule the readings of different trials would duplicate quite closely, but occasionally they would be far apart. The difference and trend of the general results, however, are so definite and preponderant that a slight lack of duplication has not much significance. For instance the effect of the different concentrations of any salt on any soil is very large and definite.

An examination of the experimental results presented in the tables reveals many important and interesting facts in regard to the rate and character of slaking of soils as influenced by different chemical reagents of various concentrations. In the first place, it is immediately seen that the rate of slaking varies tremendously with the concentration. Taking water as a standard, the time required for some soils to slake or disintegrate varies from about 20 minutes in water to more than 7 hours in the highest concentrated solution. Thus, Grundy silt loam slaked in about 20 minutes in water, but in

TABLE 1.—*Rate and character of slaking of different soils in NaCl solutions of various concentrations.*

	Minutes in					
Soils	H_2O	1N	3N	5N	7N	Remarks
Michigan sandy loam	2	2	3	3½	6	Soil slaked into fine particles.
Michigan silt loam	5	6	6	9	10	Soils slaked into fine particles.
Napanee silt loam	6	6	7	7	7	Soil slaked into fine particles.
Memphis silt loam	25	35	55	105	135	Soil slaked into fine particles.
Grundy silt loam	20	15	60	150	180	In highest concentration soil crumbled into large pieces.
Palouse silt loam	20	23	55	105	120	Soil slacked into small flakes.
Minnesota Carrington clay loam	4	5	16	35	60	In most concentrated solutions soil tended to crumble.
Brookston clay loam	55	60	60	75	85	Soils tend to crumble rather than slake.
Saginaw clay loam	22	40	50	80	95	In higher concentrations soil tended to crumble into coarse material.
Clyde clay	6	6	7	8	11	Soil slaked into fine particles.
Pierre clay	16	20	55	120	150	In highest concentration soil crumbled into large pieces.
Yolo clay	16	25	50	80	130	Soil slaked into small flakes in all solutions.
Illinois Red clay	20	35	55	70	120	In most concentrated solutions the soil crumbled.
Houston black clay	2	2	2	3	3	Soil slaked into very fine particles.

7 N NH_4NO_3 it required about 6 hours to disintegrate. California Yolo clay slaked in about 17 minutes in water, but it required more than 7 hours to break up in 7 N $CaCl_2$.

The rate of slaking varies not only with the concentration but also with the kind of reagent and the soil. Some soils will slake much faster than others in the same reagent and concentration. Thus, in any reagent, Michigan silt loam, Napanee silt loam, and a few others slake much faster than such soils as Grundy silt loam, Memphis silt, and Palouse silt loam, to say nothing of some of the

TABLE 2.—*Rate and character of slaking of different soils in KCl solutions of various concentrations.*

	Minutes in				
Soils	H_2O	1N	3N	5N	Remarks
Michigan sandy loam	1½	1½	2	2½	Soil slaked into fine material.
Michigan silt loam	3½	3½	3½	6	Soil slaked into very fine particles.
Napanee silt loam	5	6	7	10	Soil slaked into very fine particles.
Grundy silt loam	22	95	300	400	In solutions soil crumbled into very large pieces.
Palouse silt loam	25	110	180	240	No slaking in high concentrations but crumbled in large pieces.
Brookston clay loam	55	85	120	150	Soil in solutions crumbled into large pieces.
Saginaw clay loam	22	35	45	60	In highest concentrations soil crumbled into coarse material.
Pierre clay	18	40	240	350	In solutions soil split into large pieces.
California Yolo clay	18	35	50	70	In highest concentration soil crumbled into coarse material.
Clyde clay	18	20	33	35	In solutions soil crumbled in flat flakes.

TABLE 3.—*Rate and character of slaking of different soils in $CaCl_2$ solutions of various concentrations.*

	Minutes in					
Soils	H_2O	1N	3N	5N	7N	Remarks
Michigan sandy loam	1½	1½	2½	3½	10	Soil slaked into fine material.
Michigan silt loam	4	5	7	15	55	Soil slaked into fine particles.
Napanee silt loam	5	6	10	13	60	Soil slaked into fine texture in all solutions.
Grundy silt loam	20	23	60	90	140	In highest concentration soil crumbled into large pieces.
Palouse silt loam	25	50	60	80	None	Soil in 7N at end of 4 hours still intact.
Brookston clay loam	55	60	60	65	180	In highest concentration soil not slaked but crumbled.
Saginaw clay loam	23	30	35	60	210	In highest concentration soil crumbled into large pieces.
Pierre clay	18	21	35	80	None	At end of 15 hours ball in 7N still intact.
California Yolo clay	17	28	45	85	420	Texture is flaky in all solutions except in 7N where it is crummy.

TABLE 4.—*Rate and character of slaking of different soils in Na_2SO_4 solutions of various concentrations.*

Soils	Minutes in H_2O	1N	3N	5N	Remarks
Michigan sandy loam	2	2	2	2½	Soil slaked into very fine particles.
Michigan silt loam	5	5	5	5	Soil slaked into very fine particles.
Napanee silt loam	4½	4½	5	5	Soils slaked into very fine particles.
Grundy silt loam	20	20	35	50	Soil slaked into fine particles.
Palouse silt loam	23	28	35	42	Soil slaked into fine particles.
Brookston clay loam	50	40	40	40	In solutions soil slaked faster and in fine particles.
Saginaw clay loam	23	35	40	50	Soil slaked into fine particles.
Pierre clay	16	18	20	22	Soil slaked into fine particles.
California Yolo clay	17	20	28	38	Soil slaked into fine particles.
Clyde clay	9	10	11	13	Soil slaked into fine particles.

TABLE 5.—*Rate and character of slaking of different soils in NH_4NO_3 solutions of various concentrations.*

Soils	Minutes in H_2O	1N	3N	5N	7N	Remarks
Michigan sandy loam	1½	2	2	2½	3	Soil slaked into fine material.
Michigan silt loam	4	4	4	4½	7	Soil slaked into fine particles.
Napanee silt loam	4½	6	6	8	11	Soil slaked into fine particles.
Grundy silt loam	21	90	180	230	400	In highest concentration soil broke into large pieces.
Palouse silt loam	24	70	120	160	240	In highest concentration soil crumbled into large pieces.
Brookston clay loam	55	85	130	180	210	In solutions soil would crumble into large pieces.
Saginaw clay loam	23	40	45	48	60	Soil crumbled to various sizes in solutions.
Pierre clay	17	25	60	70	70	In 3 highest concentrations soil crumbled into large pieces.
California Yolo clay	18	33	36	50	65	Slaked into flaky flat pieces of different sizes.
Clyde clay	9	22	38	40	48	In solutions soil crumbled into various sizes.

TABLE 6.—*Rate and character of slaking of different soils in HNO_3 solutions of various concentrations.*

	Minutes in					
Soils	H_2O	1N	3N	5N	7N	Remarks
Michigan sandy loam	1½	1½	1¾	20	2½	Slaked into fine material.
Grundy silt loam	22	30	120	None	None	In highest concentrations soil broke only into large blocks.
Palouse silt loam	25	20	20	150	None	In highest concentrations soil remained intact.
Brookston clay loam	56	30	40	120	None	In highest concentrations soil remained intact.
Saginaw clay loam	24	45	90	95	105	Crumbled into medium coarse material.
California Yolo clay	18	25	55	150	300	Crumbled into flaky texture.

TABLE 7.—*Rate and character of slaking of different soils in KOH solutions of various concentrations.*

	Minutes in					
Soils	H_2O	1N	3N	5N	7N	Remarks
Michigan sandy loam	1½	5	6	17	20	Soil slaked into fine material.
Michigan silt loam	4	6	6	12	15	Soil slaked into fine material.
Grundy silt loam	21	125	None	None	None	In highest concentrations soil stays intact.
Brookston clay loam	54	None	None	None	None	Soil stays intact in all concentrations.
Pierre clay	22	30	None	None	None	Soil stays practically intact.
California Yolo clay	18	30	50	65	100	Soil crumbled into medium small pieces.

TABLE 8.—*Rate and character of slaking of different soils in sugar solutions of various concentrations.*

	Minutes in			
Soils	H_2O	10%	40%	Remarks
Michigan sandy loam	1½	2	6	Slaked into fine material.
Grundy silt loam	23	30	120	Slaked into fine material.
Palouse silt loam	25	30	130	Slaked into fine material.
Memphis silt loam	25	30	90	Slaked into fine material.
Brookston clay loam	55	65	140	Slaked into fine material.
Saginaw clay loam	24	26	65	Slaked into fine material.
California Yolo clay	17	25	120	Slaked into fine material.

clay loams and clays. The Napanee silt loam, for instance, slaked in 7 minutes in 7 N NaCl, while it took 180 minutes for the Grundy silt loam to break up in the same solution and concentration.

The rate of slaking of the same soil in different reagents differs considerably, especially with some soils. Grundy silt loam, for instance, slaked in 50 minutes in 5 N Na_2SO_4, but it took the same soil 400 minutes in KCl, 150 in NaCl, 230 in NH_4NO_3, and 90 in $CaCl_2$, all of the same concentration. Pierre clay slaked in 22 minutes in 5 N Na_2SO_4, but it required 70 minutes to crumble in NH_4NO_3, 120 in NaCl, 350 in KCl, and 80 in $CaCl_2$. Those soils which tended to slake rapidly, such as the Napanee silt loam, did not differ very much in their rate of breaking down in the various reagents, but all the other soils varied considerably.

Not only does the kind of reagent and degree of concentration affect the rate of slaking of soils but also the character of slaking. Indeed, the texture and structure of the slaked material varies greatly both within the same reagent of different concentrations and between different reagents. Some soils, such as the Michigan sandy loam, Napanee silt loam, etc., tended to slake into fine material in almost all of the reagents and in nearly all of the concentrations. Also, in some reagents like Na_2SO_4, all the soils tended to slake into fine particles in all the different concentrations. Again, some soils, such as the Decatur clay, would not slake at all, either in water or in any concentration of the different reagents, but would merely break up into large pieces. But the majority of soils tended to slake or break down into coarser material as the concentration of the different reagents increased. In water and in the most dilute concentration these soils would slake into fine or very fine material, but as the concentration increased they would break down into coarse material and in the highest concentrations they would break down into very large pieces or not break down at all, but the balls would stay intact indefinitely.

As a matter of fact, in the highest concentrations, including 7 N, 5 N, and even 3 N in some reagents, many of the soils do not really slake but crumble into coarse material or into very large pieces after the balls become thoroughly soaked. The reagents in which many soils would break down into large pieces at the highest concentration or, sometimes, would not break down at all were KCl, $CaCl_2$, KOH, and HNO_3.

As a general rule, whenever a soil failed to slake in some reagents or at the higher concentrations but would break down into large pieces or would not break down at all, it would feel dry and hard to touch and would not work into a plastic condition, even though it was entirely wet. Such a soil would appear contracted and would not become saturated with the liquid, no matter how long it was allowed to remain in the latter. Thus, for instance, nearly all of the clay soils which were allowed to stay for many hours in the higher concentrations of KCl, $CaCl_2$, KOH, and HNO_3 until they were entirely wetted still appeared contracted, unsaturated, and hard and dry to the touch. In some reagents, such as HNO_3, the soils would even fall into powder upon crushing, even though they were entirely wet. There would be absolutely no plasticity in these soils.

POSSIBLE CAUSES OF THE PHENOMENA

There appear to be several causes for the marked difference in the rate and character of slaking in soils which are obtained in the different reagents and in the various concentrations of the same reagent. Probably the most important cause is to be found in the ability of the reagent or concentration to flocculate or deflocculate or to fail to exert any influence on the soil or its colloids. The condition of soils which appear contracted, nonplastic, hard and dry, and break down into large pieces or blocks in certain reagents and concentrations can be reasonably explained only on the basis that such soils are flocculated or coagulated. Those soils which disintegrate or slake into fine particles or material are either deflocculated by the reagents or are not influenced at all, but their particles fall apart as a result of the interposed film of liquid reducing the cohesion of the soil grains. It appears, therefore, that when a soil is coagulated by a reagent or concentration, its rate of disintegration is slower than it is when the same soil is deflocculated or not influenced at all by a reagent or concentration. When a soil is coagulated and the particles stay intact the liquid experiences greater friction and penetrates the soil at a slower rate, and consequently the disintegration is less rapid.

A second important factor which seems to exert an important influence on the rate of disintegration of soil masses is the rate at which the liquid is absorbed by or penetrates the soil. It was found that many reagents, especially at the highest concentrations, would enter or penetrate the soil ball at an exceedingly slow rate. For instance, at the end of two hours the balls of such soils as Grundy silt loam, California Yolo clay, and Illinois red clay in the higher concentration of $CaCl_2$, KCl, KOH, and HNO_3 would be wetted less than half way through and in some instances only about a quarter through, although in water they would slake completely in about

20 minutes. The liquids in these cases, therefore, penetrated the soils quite slowly. When the liquids had penetrated the balls clear through and the latter became saturated, thev would break first into large pieces and finally would crumble into smaller pieces.

One of the primary objects which prompted this investigation was the desire to ascertain whether a soil would absorb a solution of different concentrations at the same or different rates. It was reasoned that since the osmatic pressure and viscosity of a solution increases with concentration, the soil should absorb the solution with greater difficulty as the concentration increased. On the other hand, it was thought that if the soil absorbs the solution as a whole physically and not the water alone, then concentrations should play very little part so far as osmatic pressure is concerned.

Although osmatic pressure and viscosity may influence somewhat the rate at which the soil absorbs the solution, it would appear that this influence is probably very small, and that the greatest influence from the concentration comes more from its effect on the physical condition of the soil rather than from the osmatic pressure. This view would seem to be supported both from the fact that soil tends to absorb the solution as a whole physically (in a broad sense) and also from the fact that where the soil is not coagulated but slakes readily the absorption of the solution is quite rapid, even at the highest concentrations.

This type of experimental results should have some bearing on the washing out or gullying of soils.

SUMMARY

Blocks of dry soils, or soils made into balls and dried, tend to disintegrate or slake into their ultimate single particles or into compound particles or to crumble into small pieces when placed in an excess of water.

An attempt was made to investigate the influence of different reagents of various concentrations upon the rate and character of slaking of soils of different types. The reagents employed included salts, bases, and acids in the concentrations of 1 N, 3 N, 5 N, and 7 N.

It was found that the rate and character of slaking depended upon the kind of reagent, degree of concentration, and type of soil. Some soils slaked at a very rapid rate and in very fine particles in all of the different reagents and in all the various concentrations used. Other soils slaked or disintegrated at a diminishing rate as the concentration increased in all the different reagents. Taking water as a standard, the time required for some soils (made into balls) to slake or disintegrate varied from 20 minutes in water to more than 7 hours in the highest concentrated solution of some reagents.

The rate of slaking varied not only with the concentration but also with the kind of reagent and soil.

Not only did the kind of reagent and concentration affect the rate of slaking, but also the character of slaking. Some reagents caused the soil to slake into fine particles at all concentrations, while other reagents caused the same soils to disintegrate or break down into coarser or larger pieces as the concentration increased.

A DEFECTIVE ENDOSPERM IN THE HETEROZYGOUS CONDITION AS RELATED TO YIELD IN MAIZE[1]

R. J. Garber and H. K. Rowley[2]

The genetics of the corn plant is perhaps better known than that of any other plant. This is the direct outcome of intensive studies that have been carried on at several institutions. Numerous characters which are considered as abnormal when isolated in a homozygous condition have been discovered. These so-called "abnormalities" when in a homozygous condition interfere with the normal growth and metabolism of the plant, although in the heterozygous condition the same "abnormalities" may be carried indefinitely without any apparent harmful effect. Many of the present practices in technical corn breeding are based on the belief that the elimination of the characters which when homozygous are deleterious to growth will result in increased yields. As a matter of fact, little is definitely known concerning the influence on yield of these deleterious characters when in a heterozygous condition. A few studies bearing on this question have been reported. Some of these are briefly reviewed below.

The purpose of the present paper is to give the results of an experiment to determine the influence of a certain defective endosperm character in a heterozygous condition on yield, height of plant, and number of nodes.

LITERATURE REVIEW

In a study of methods of maize breeding with a single variety, Collins (1)[3] found a negative correlation of —0.48 ±0.12 between

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[1] Approved by the Director for publication as Scientific Paper No. 36 from West Virginia Agricultural Experiment Station, Morgantown, W. Va. Received for publication May 12, 1927.

[2] Agronomist and seed analyst, respectively.

[3] Reference by number is to "Literature Cited," p. 803.

the percentage of abnormalities and length of ear among 20 strains of corn that had been selfed one year. Since length of ear and yield are positively correlated, it would seem that the relatively high number of abnormalities in certain strains tended to reduce yield. Jones and Mangelsdorf (3) grew 25 progenies segregating for abnormalities and 25 progenies from which the abnormalities had been eliminated in adjoining rows and found no significant difference in yield.

Lindstrom (5 and later papers) has worked out in considerable detail the inheritance of chlorophyll abnormalities in maize. He observed that a certain abnormality (albino seedling) in the heterozygous condition was associated with weak stalks.

A rather intensive study of the inheritance of several different defective endosperm characters has been made by Mangelsdorf (6). No significant difference in height of plant between strains segregating for a defective endosperm and those which bred true for normal seed was found, although it was observed that ears segregating for a defective endosperm were somewhat smaller than normal ears.

Kyle and Stoneberg (4) in a study of selfed strains found that those which were most productive had relatively fewer heritable deleterious characters than the strains that were less productive.

MATERIAL AND METHODS

The source of material used in this investigation has been described in two previous publications (2 and 7). One of the selfed strains of maize isolated from the variety Leaming produced a selfed ear in 1922 that segregated for a defective endosperm character. By successive self-pollinations of plants heterozygous for this character the strain was carried for two years more before crosses were made.

In 1924 homozygous normal plants of this particular strain which had now been selfed for four years were crossed with plants homozygous for the defective endosperm of the same strain. Some of the homozygous normal plants were selfed. This procedure was repeated in 1925 with the same heterozygous strain which had now been selfed for five years.

The seed obtained from crossing the normals with the defectives, as well as that obtained by selfing the normals, was grown so as to test its relative yielding capacity. The two kinds of seeds and the plants grown from them will be designated as "heterozygous defective" and "normal," respectively. The seed for the yield tests in 1925 and 1926 was produced in each case the preceding year.

In addition to yield of air-dry shelled corn of individual plants, notes were taken on height of plant in inches and on number of nodes.

Data on infection with smut and on root rot were also taken. All smutted plants as well as those badly infected with root rot were discarded.

In 1925, seed from five different heterozygous defective ears and five different normal ears were planted. The plants were grown in such a way as to permit the study of the progeny of each ear separately. The normal and the heterozygous defective seeds were planted in alternate hills and vice versa. The rows were 3 feet 6 inches apart and the hills were spaced 30 inches apart in the row. Two to four seeds per hill, depending on the number available, were planted and later each hill was thinned to a single stalk. A total of 225 hills of each kind of seed was planted.

A similar planting plan was followed in 1926 with the exception that the hills were spaced 3 feet 6 inches each way so as to allow more space for each plant to develop. During this year no attempt was made to keep the seed of individual ears separate. Two heterozygous defective ears and three normal ears furnished the seed for the test in 1926. In all there were planted 221 hills of normal and 221 hills of heterozygous defective seed. Later each hill was thinned to a single stalk as in 1925.

EXPERIMENTAL DATA

The experimental data presented below are not extensive, but the results for the two years are in the main consistent. Individual plant yields were taken rather than the yield of plats, owing to the necessity of working with a rather small number of plants and owing also to the limited area available for carrying on the test. By planting in alternate hills replication was sufficient to eliminate effectively the influence of soil heterogeneity. It may be objected, however, that this same practice did enhance very materially the matter of competition between the normal and heterozygous defective plants. As a matter of fact, it was not possible to detect such competition if it did exist. The correlation coefficients between the yields of normal plants and of heterozygous defective plants in adjacent hills in the same row were determined and found not to be significant. In 1925, $r=0.025 \pm 0.81$, and in 1926, $r=0.093 \pm 0.057$. If the higher yields of normal plants tended to depress the yields of heterozygous defective plants, one would expect a negative correlation. On the other hand, one would expect marked soil heterogeneity to be expressed as a positive correlation. It is possible that these two tendencies counteracted one another.

Normal plants and heterozygous defective plants were not distinguishable in the field. For this reason and on account of the fact that each individual plant had sufficient space for development, it is thought that competition was of minor importance in this experiment.

INFECTION WITH ROOT ROT

The strain of corn used in this study unfortunately was susceptible to root rot. The infection in both 1925 and 1926 was rather heavy but in neither year was a significant difference observed between the normal and the heterozygous defective plants with regard to the relative number infected with root rot. In 1925, among a total of 184 normal plants, 24 were stunted and 21 killed prematurely owing to root rot, whereas among 110 heterozygous defective plants, 7 were stunted and 7 were killed. The relatively small total number of heterozygous defective plants obtained in 1925 was owing to the fact that the seed from one of the ears planted gave very poor germination.

In 1926, out of a total of 200 normal plants, 19 were stunted and 10 killed prematurely by root rot, whereas among 179 heterozygous defective plants, 12 were stunted and 4 were killed. These data indicate that if there is any real difference between the normal and the heterozygous defective plants the former are the more susceptible. This is mentioned to show that the difference between the yields obtained from these two kinds of plants cannot be attributed to a difference in the degree of infection with root rot.

RELATIVE NUMBER OF NODES

The mean number of nodes of the normal plants was 10.52 ±0.06 and of the heterozygous defective plants 10.41 ±0.07. It is obvious that no significant difference exists between these two values. In 1926 the number of nodes was not determined.

RELATIVE HEIGHT

The height notes were recorded to the nearest inch only. In 1925 the mean height of the normal plants was 68.67 ±0.62 and of the heterozygous defective plants 73.87 ±0.74, whereas the mean heights in 1926 were 70.0 ±0.37 and 69.78 ±0.41, respectively. There was obtained in 1925 a difference of 5.20 ±0.96 inches in favor of the heterozygous normal plants and in 1926 a difference of 0 22 ±0.55 inch in favor of the normal plants. The latter difference is not significant. Probable errors were computed by using the approximation formula $(E_{\text{diff}} = \sqrt{e_1^2 + e_2^2})$. The difference obtained in 1925 between the mean heights of the two kinds of plants is considerable and can scarcely be attributed to chance. In this connection it should be borne in mind that the seed used for the comparison in

1925 was produced after the strain had been selfed for four years, whereas that used for the comparison in 1926 was produced after the strain had been selfed for five years. The height notes alone indicate that the heterozygous defective plants grown in 1925 were somewhat more vigorous than the normal plants grown the same year.

RELATIVE YIELD

Individual plant yield was determined for each plant harvested in both years this study was under way. All the corn from each plant was placed in a separate bag and hung in a drying room artificially heated. After the ears were dry the corn was shelled and the yield of shelled corn in grams determined. The data are presented in Table 1.

The frequency distributions show a wide dispersion and each shows indications of being bi-modal. There is a distinct piling up of variates at the extreme left of the distributions, with the yields of heterozygous defective plants showing this tendency to a greater degree than those of the normal plants.

The mean yields are shown in the last column of Table 1. In 1925 the 151 normal plants produced a mean yield of 95.89 ±2.37 grams, whereas the 97 heterozygous plants produced a mean yield of 71.03 ± 3.36 grams. The difference, which is approximately 26% of the mean yield of the normal plants, is significant and indicates that the presence of the factor for defective endosperm caused a reduction in yield.

Similar results were obtained in 1926. The 182 normal plants produced a mean yield of 63.46 ±1.80 grams and the 169 heterozygous defective plants produced a mean yield of 49.72 ±1.92 grams, the difference being approximately 22% of the mean yield of the former.

DISCUSSION AND CONCLUSIONS

The ordinary commercial varieties of corn carry numerous genetic factors which when isolated in a homozygous condition seriously interfere with normal metabolism and growth. A considerable part of the genetic literature of maize deals with the manner of inheritance of "abnormal" characters, although there is little known about the effect on yield of these same characters in a heterozygous condition. This phase of corn breeding work deserves more attention than it has received.

Many of the present practices of technical corn breeding are based on the assumption that all characters which, when in a homozygous condition are deleterious to growth, should be eliminated.

TABLE 1.—*The frequency distributions and means in yield of shelled corn per plant of "normal" and heterozygous "defective" plants grown at Morgantown, W. Va., in 1925 and 1926.*

Name	Year	Mid-classes in grams																				n	Mean
	grown	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170					
Normal	1925	10	6	5	6	5	4	7	7	10	18	9	17	19	17	3	6	2				151	95.89±2.37
Heterozygous defective	1925	15	13	5	7	5	3	3	6	3	7	6	6	4	6	6	2					97	71.03±3.36
		Mid-classes in grams																					
		10	17	24	31	38	45	52	59	66	73	80	87	94	101	108	115	112	129	136	143		
Normal	1926	20	10	7	19	6	7	7	10	11	12	13	14	8	8	12	7	5	4	1	1	182	63.46±1.80
Heterozygous defective	1926	40	21	10	5	11	6	9	1	9	7	9	5	12	11	5	3	1	2	2		169	49.72±1.92

This seems reasonable, yet it is not only possible but quite likely that there is considerable difference between the effect on yield of these so-called deleterious characters in a heterozygous condition. The factors which have the greatest effect in reducing yield naturally should be eliminated first.

The data presented in this paper show the effect on yield, height of plant, and number of nodes of a certain defective endosperm in the heterozygous condition in a strain of Leaming corn which had been selfed for four and five years. This character, when homozygous, has a profound influence on the growth of the plant (7), yet when in the heterozygous condition growth of the plant is apparently very little affected. In the field, heterozygous defective plants of this strain could not be distinguished from homozygous normal plants. On the other hand, the mean yield of the normal plants in 1925 was about one-third and in 1926 one-fourth more than the respective mean yields of the heterozygous defective plants. The weight of the normal and of the heterozygous defective seed planted was about the same. The strain of Leaming corn used in this experiment was rather susceptible to root rot. The degree of infection of the normal and heterozygous defective plants was approximately the same, and hence the difference in yield could not be attributed to this disease.

With respect to mean height of plant in 1925 a difference of 5.20 ±0.96 inches in favor of the heterozygous defective plants was found, whereas in 1926 the difference in mean height was 0.22 ±0.55 inch in favor of the normal plants. The latter difference is not significant.

The number of nodes per plant was determined in 1925 only. No significant difference was found between the two kinds of plants.

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MORPHOLOGICAL AND CYTOLOGICAL STUDIES OF AN OAT FROM ETHIOPIA[1]

T. R. Stanton and E. Dorsey[2]

INTRODUCTION

During his recent plant explorations in North Africa in search of new barleys for use in the United States, H. V. Harlan, agronomist in charge of barley investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, collected in Ethiopia some seeds of an oat which apparently represents a cultivated form of *Avena abyssinica* Hochst., as described by Trabut (8).[3] At the request of the writers Doctor Harlan has prepared the following statement of the occurrence and culture of oats in Ethiopia (Abyssinia).

"Oats do not occupy the place in Ethiopian agriculture that analogy would define for them. Being cool weather plants their culture might be expected to center on the mountain tops. As the crop is unimportant and apparently only incidentally cultivated, the half-wild stages that Vavilov found in Asia would be expected to exist. In the limited observations I was able to make, neither expectancy is fulfilled. The high cool mountain tops are given over entirely to barley. On the secondary ridges, but still over 9,000 feet, I found oats in only two fields. It is true that there is a second harvest in July the nature of which is unknown to me, but in the principal harvest oat plants are rare at the higher elevations.

"While not plentiful, oats frequently were observed in the Galla villages at about 5,000 feet elevation. There is here a possibility, of course, of racial preference. Among both Amharas and Gallas all oats occurred as mixtures in barley fields. The Galla growers told me they were seeded there intentionally, which I took to be a truthful statement, as most barley fields were free from oats. Among the Gallas oats are seeded with barley of the *deficiens* type. This sort of barley is not grown high on the mountains.

"I looked carefully for wild or escaped plants of oats. I saw neither. There are two possibilities as to the status of oats. If present as a wild plant it must fruit at a different season, or it must be rare. If it does not exist in the wild state the culture of oats must be old in Ethiopian agriculture."

A few months after the receipt of the samples of seed from Harlan,

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[1] Cooperative investigations conducted by the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C., and the Department of Plant Breeding of Cornell University, Ithaca, N. Y. Received for publication May 18, 1927.

[2] Agronomist in charge of oat investigations, Office of Cereal Crops and Diseases, and Instructor in Plant Breeding at Cornell University and agent of the Office of Cereal Crops and Diseases, respectively.

[3] Reference by number is to "Literature Cited," p. 818.

the same oat was presented to the Office of Foreign Plant Introduction, Bureau of Plant Industry, U. S. Department of Agriculture, by the director of an agricultural experiment station at Asmara, Eritrea, Africa. That Office recorded (10, 11, 12) the introduction of these oats from Ethiopia and Eritrea as follows:

58725 to 58730.

From Addis Ababa, Abyssinia. Seeds collected by H. V. Harlan, Bureau of Plant Industry. Received February 26 and March 14, 1924. Field notes by Doctor Harlan.

Collected in Modjo, Abyssinia.

. . . .

58727. *Avena abyssinica* Hochst. Poaceae. OATS.

(No. 292. November 11, 1923.) Selected in a field of mixed oats and barley; said to be seeded with the barley.

58728. *Avena strigosa* Schreb. Poaceae. OATS.

(No. 304. November, 1923.) Panicles from a field of barley.

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60461 to 60636. From Abyssinia. Seeds collected by H. V. Harlan, Bureau of Plant Industry. Received June 3, 1924. Notes by Doctor Harlan.

60463. *Avena abyssinica* Hochst. Poaceae. OATS.

No. 399a. December 8, 1923. From a threshing field on the road to Ankober, at an altitude of 9,600 feet.

60540 to 60546. *Hordeum vulgare pallidum* Seringe. SIX-ROWED BARLEY.

60540. No. 399b. December 8, 1923. From a threshing field on the road to Ankober, at an altitude of 9,600 feet. (Contained oat seeds as an admixture.)

60541. No. 405. December 9, 1923. Collected one day's journey west of Ankober, at an altitude of 9,600 feet. (Contained oat seed as an admixture.)

61272. *Avena abyssinica* Hochst. Poaceae. OATS.

From Asmara, Eritrea, Africa. Seeds presented by the Direttore dell Ufficio Agrario Sperimentale. Received August 1, 1924.

In the upper part of the middle, or subtropical zone, of Abyssinia, where the altitude is approximately 8,000 feet, and also at still higher altitudes in some places, this species of oat is cultivated both as a cereal and for forage, according to Chiovenda (Osservazioni Botaniche, Ethiopia). Besides the typical form, a number of local strains have been reported.

The original lots of seed, bearing Foreign Seed and Plant Introduction Nos. 58727, 58728, 60463, and 61272, were recorded as accessions under Cereal Investigations accession numbers 2108, 2109, 2110, and 2113, respectively. The seed which was obtained as admixtures in the barley introductions, bearing Foreign Seed and Plant Introduction Nos. 60540 and 60541, listed in the above inventory, was recorded as accessions under Cereal Investigations Nos. 2112 and 2111, respectively. Unfortunately, the seed to which

C. I. No. 2111 had been assigned failed to germinate, and, as a consequence, this introduction was lost.

The separate lots of seed received from Harlan, and the one from Eritrea, were sown in the detention nursery at the U. S. Field Station, Sacaton, Ariz., in the fall of 1924, for determination of their freedom from plant disease. These mass strains were grown in nursery rows at the Aberdeen Substation, Aberdeen, Idaho, in 1926, where the observations on morphological characters presented in this paper were made.

MORPHOLOGICAL CHARACTERS

As previously stated, plant populations were grown at Aberdeen, Idaho, in 1926, from seed of each of the five original mass strains which had been grown at Sacaton, Ariz., in 1925. Differences between these mass strains, and also differences between plants within each strain, were noted. A description covering the oat form represented follows.

Avena abyssinica HOCHST.

History.—As previously noted, this cultivated form of the Abyssinian oat was obtained in Ethiopia in 1923, by H. V. Harlan during an exploration trip in search of new barleys for use in the United States. It is believed that this new oat may be of value for plant-breeding purposes, that is, for the development of very early, drought-resistant strains especially adapted to dry climates and high altitudes.

Description.—Juvenile growth erect; plant very early in maturity. Culms erect, slender to midsized, fairly rigid, 50 to 90 cm tall; nodes glabrous. Sheaths deep green, pubescent; culm leaves linear, margins ciliate. Peduncle slender to midsized, not always fully exserted. Panicle nodding, equilateral, ovate, midsized to large, 15 to 30 cm long, rachis nodes 5 to 7; branches midlength to long, scabrous, and usually drooping. Spikelets numerous, usually 2-flowered, separating from the supporting rachilla segment (pedicel) by fracture; florets slender, separating by disarticulation of second (and third) rachilla segment. Glumes boat-shaped, 18 to 26 mm long, 5 to 6 mm wide, usually 9-veined, light green before maturity. Lemmas ovate-lanceolate, indurate except toward the apex; glabrous, white, gray or black. First lemma 15 to 22 mm long, biaristate, the points 2 to 4 mm long; basal hairs few or absent; awn always present, twisted and geniculate, 20 to 30 mm long. Second lemma 11 to 16 mm long, biaristate, the points 1 to 3 mm long; awn always present, twisted and geniculate, 15 to 25 mm long. Second rachilla segment slender, cylindrical, 2 to 4 mm long, pilose; hairs usually

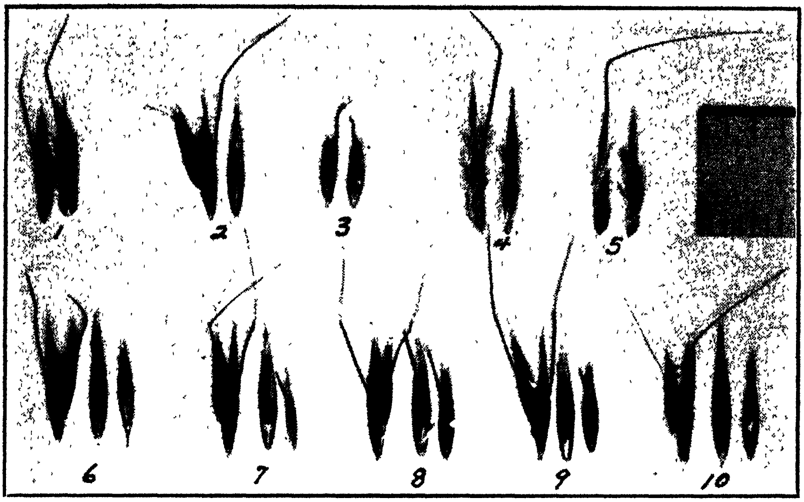

FIG. 1.—Florets and spikelets of oat forms (1) *Avena wiestii*, (2) *A. strigosa*, (3) *A. brevis* (not described in this paper), (4) *A. barbata* (from Russia), (5) *A. barbata* (from California), (6, 7, 8, 9, 10) *A. abyssinica*, C. I. Nos. 2108, 2109, 2110, 2112, and 2113, respectively.

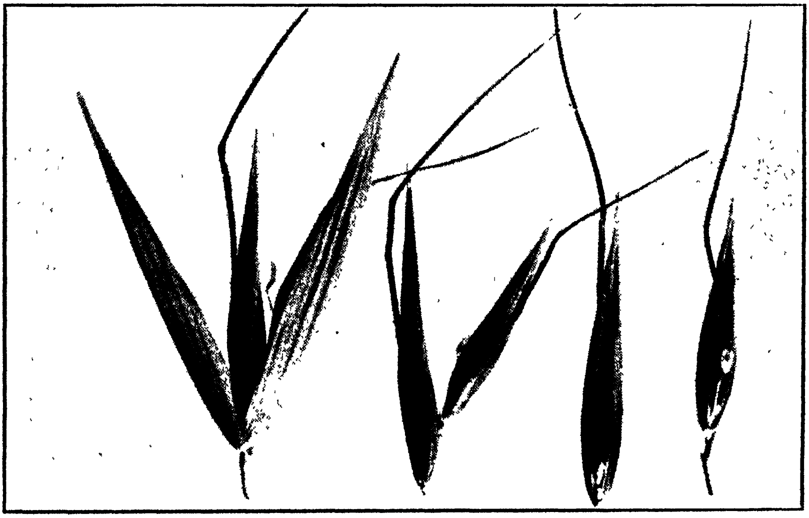

FIG. 2.—Spikelets and florets of *Avena abyssinica*, C. I. No. 2108. (Enlarged about 2½ times)

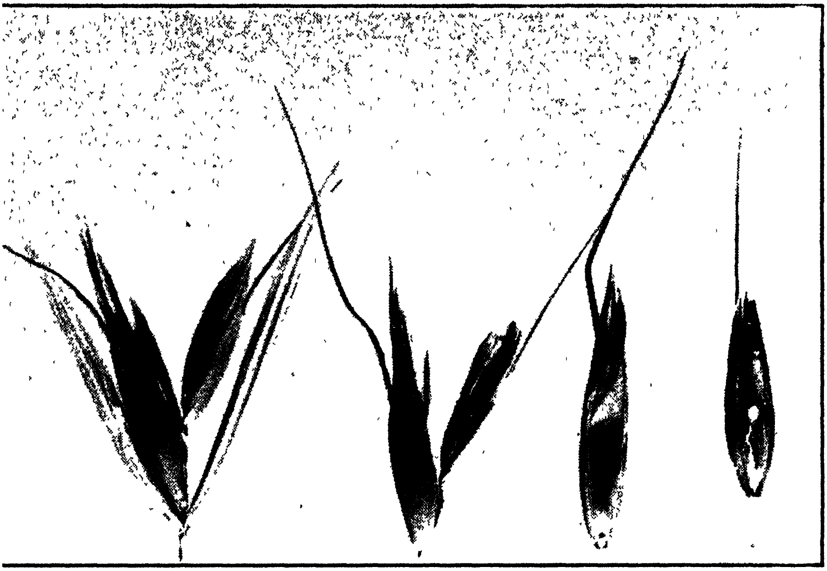

FIG. 3.—Spikelets and florets of *Avena abyssinica* C. I. No. 2109. (Enlarged about 2½ times)

abundant on upper half, 0.5 to 1.5 mm long, progressively longer toward the apex, giving it a plumose appearance.

The following brief field notes were made on each of the five mass strains.

C. I. No. 2108.—The plants were variable in color of lemma. The 5-foot row contained 1 black-, 6 white-, and 15 gray-seeded plants, all of which, however, were similar in other plant and kernel characters. The average height of plant was about 75 cm. (See Figs. 1 and 2.)

C. I. No. 2109.—A mixture of gray-seeded and white-seeded plants of the same general type as C. I. No 2108. However, as a group, the plants were a little earlier than those. (See Figs. 1 and 3.)

C. I. No. 2110.—A mixture of gray- and black-seeded plants of the same general type as C. I. No. 2108. (See Figs. 1 and 4.)

C. I. No. 2112.—The panicles were not as well exserted as in the three preceding mass strains (growth may have been checked by lack of irrigation water), although the plants were a little taller and a little later in maturity. Otherwise this strain was similar to those represented by C. I. Nos. 2108, 2109, and 2110. The plant population was pure for gray lemma color. Some of the less fully developed lemmas appeared almost white, but when examined closely some gray pigment could be seen. (See Figs. 1 and 5.)

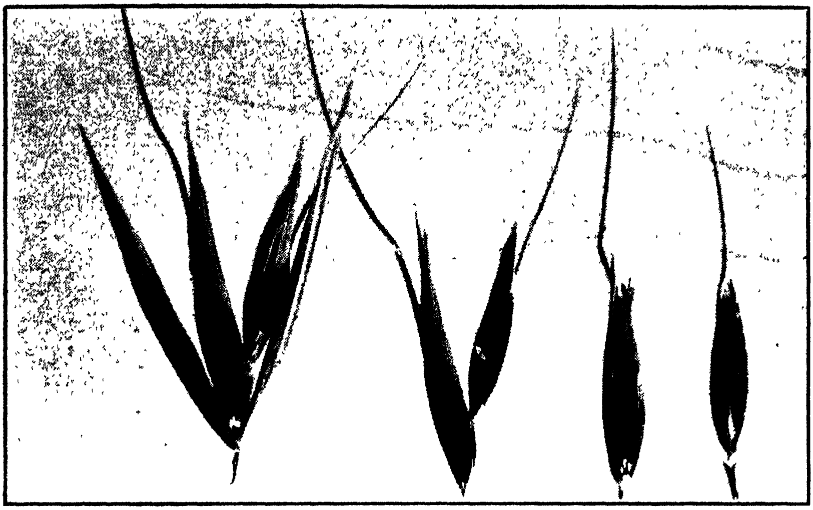

FIG. 4.--Spikelets and florets of *Avena abyssinica*, C. I. No. 2110 (Enlarged about 2½ times)

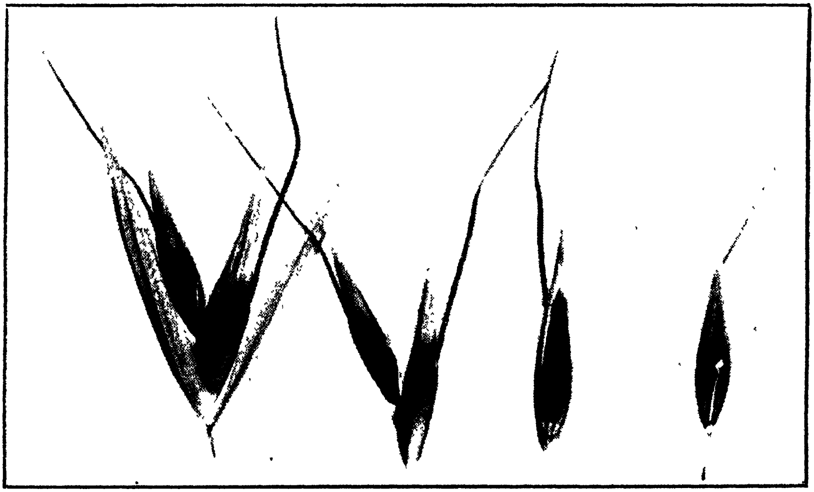

FIG. 5.—Spikelets and florets of *Avena abyssinica*, C. I. No. 2112. (Enlarged about 2½ times)

C. I. No. 2113.—This variety was the shortest in stature (55 to 75 cm) and also was the earliest in maturing of the five mass strains. The lemmas were slightly longer and there were more 3-flowered spikelets. (See Figs. 1 and 6.) Like C. I. No. 2112, it was pure for gray color of lemma. This strain was the most uniform of the lot and probably represents a distinct agronomic variety of *Avena abyssinica.* The greater uniformity of this variety would indicate that it probably had been purified by mass or line selection in Eritrea.

Aside from the character of lemma color, it is evident that no great difference exists between these mass strains. In general, all the plants grown had hairy sheaths and ciliate leaf margins. There appeared to be some slight variation in degree of hairiness of the second rachilla segment among the forms differing in lemma color, the white-kerneled form probably having the least hairs. However, from the morphological standpoint it is evident that only one botanical form is represented, and probably only three varieties with black, gray, and white kernels, respectively.

The cytological investigations of these oats are discussed later. At this juncture it seems advisable to present descriptions of *Avena strigosa* Schreb. (C. I. No. 1782), *A. wiestii* Steudel (C. I. No. 1994), and *A. barbata* Pott to show the lack of correlation of morphological characters with chromosome number in these different forms.

Descriptions of *A. brevis* Roth and *A. fatua* L. are not presented in connection with this study as these forms are so distinct and well known that there is little confusion regarding their identity.

Avena strigosa SCHREB.

History.—Seeds for this study were obtained directly from the Leningrad Botanical Garden, Russia, by the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, in 1915.

Description.—Juvenile growth semierect to erect; plant early to midseason in maturity. Culms erect, very slender, fairly rigid, 80 to 120 cm tall; nodes glabrous. Sheaths deep green, glabrous or pubescent; culm leaves linear, margins usually glabrous. Peduncle slender, not always fully exserted. Panicle erect or slightly nodding, equilateral, ovate, small, 10 to 20 cm long, rachis nodes 5 to 7; branches midlength, scabrous and usually drooping. Spikelets numerous, usually 2-flowered, separating from the supporting rachilla segment (pedicel) by fracture; florets slender, separating by disarticulation of second (and third) rachilla segment. Glumes boat-shaped, 17 to 24 mm long, 5 to 6 mm wide, usually 9-veined, light green before maturity. Lemmas ovate-lanceolate, indurate except toward the apex, glabrous, gray. First lemma 15 to 22 mm long, biaristate, the points 5 to 9 mm long; basal hairs few or absent; awn always present, twisted and geniculate, 20 to 30 mm long. Second

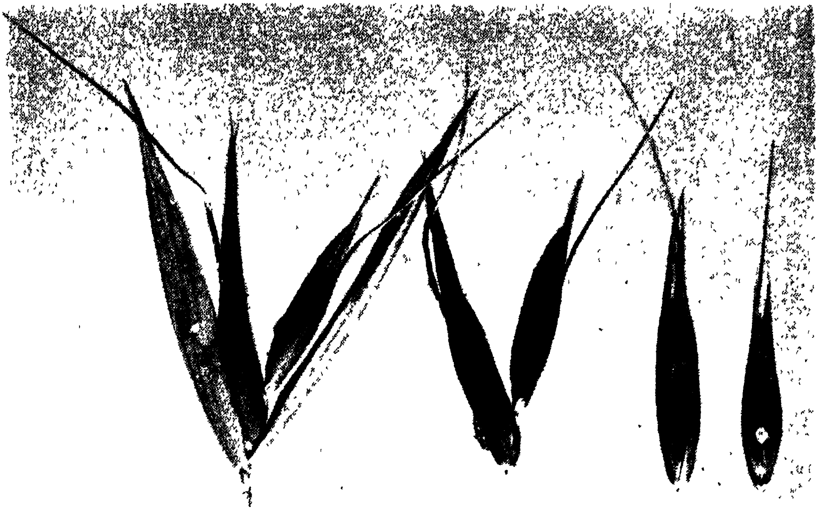

FIG. 6.—Spikelets and florets of *Avena abyssinica*, C. I. No. 2113. (Enlarged about 2½ times)

lemma 11 to 15 mm long, biaristate, the points 5 to 7 mm long; awn always present, twisted and geniculate, 15 to 25 mm long. Second rachilla segment very slender, cylindrical, 3 to 5 mm long, glabrous except for two opposite small tufts of short hairs at apex, giving a bifurcate appearance.

This form is best distinguished by its slender culm; slender lemma with two long, rather conspicuous lemma points; long, slender second rachilla segment with short hairs at its upper end, and the mode of spikelet and floret separation. It differs primarily from the Abyssinian oat as represented by C. I. Nos. 2108, 2109, 2110, 2112, and 2113 in having glabrous sheaths and leaf margins, longer and more distinct lemma points, and in having a less hairy second rachilla segment. (See Figs. 1 and 7.)

Avena wiestii STEUDEL

History.—The Office of Foreign Plant Introduction, Bureau of Plant Industry, U. S. Department of Agriculture (10) has recorded the introduction of the material studied as follows·

"53626. ***Avena barbata wiestii*** (Steud.) Hausskn. Poaceae. From Gizeh, Egypt. Seeds presented by Thomas W. Brown, director of Ministry of Agriculture, Horticultural Section. Received June 7, 1921.

An erect, sparingly hairy grass up to 2 feet in height, with linear leaves up to 7 inches long. Secured for experimental purposes."

Description.—Juvenile growth erect; plant early to midseason in maturity. Culms erect, slender, fairly rigid, 80 to 120 cm tall; nodes glabrous. Sheaths deep green, glabrous or pubescent; culm leaves linear, margins usually glabrous. Peduncle slender, usually fully exserted. Panicle erect or slightly nodding, equilateral, midsized to large, ovate, 15 to 30 cm long; rachis nodes 5 to 7; branches long, scabrous, and usually very drooping. Spikelets numerous, usually 2-flowered, separating from the supporting rachilla segment (pedicel) by abscission; florets very slender, separating by disarticulation of second (and third) rachilla segment. Glumes boat-shaped, 17 to 23 mm long, 4 to 6 mm wide, usually 9-veined, light green before maturity. Lemmas ovate-lanceolate, indurate except toward the apex, grayish brown, villous with brown hairs. First lemma 14 to 19 mm long, biaristate, the points 2 to 5 mm long; basal hairs abundant, short; awn always present twisted and geniculate, 20 to 25 mm long. Second lemma 12 to 16 mm long, biaristate, the points 1 to 4 mm long, awn always present, twisted and geniculate, 15 to 20 mm long. Second rachilla segment slender, 2 to 3 mm long, slightly flattened with slight cavity at upper end (no ring of hairs as in *A. fatua*), pilose throughout.

In spikelet and floret characters *Avena wiestii* is similar to *A. fatua*, the common wild oat, which is not described in this paper. It differs, however, in having much more slender florets with longer bristle-like lemma points and a less conspicuous cavity at the apex of the second rachilla segment, although a perfect natural separation takes place by disarticulation as in *A. fatua*. (See Figs. 1 and 8.)

Avena barbata POTT

History.—This oat constitutes one of the principal range grasses of California. It is not endemic to that region, but apparently was introduced from European or Asiatic sources. The material of *A. barbata* which was received by the Department of Plant Breeding at Cornell University from Dr. S. I Zhegalov, of the Bureau of Applied Botany, Leningrad, Russia, is similar morphologically to the California plant. The plants of the latter, however, are much less pubescent, particularly in the seedling stage, than those from the Russian seed. Florets of the two are shown in Fig. 1.

Description.—Juvenile growth semierect to erect; plant midseason in maturity. Culms erect, very slender, weak, 70 to 110 cm tall, nodes pubescent. Sheaths deep green, pubescent; culm leaves linear, margins usually ciliate. Peduncle very slender, weak, not always fully exserted. Panicle nodding, equilateral, ovate, midsized, 15 to 25 cm long; rachis nodes 5 to 7; branches short, scabrous, drooping.

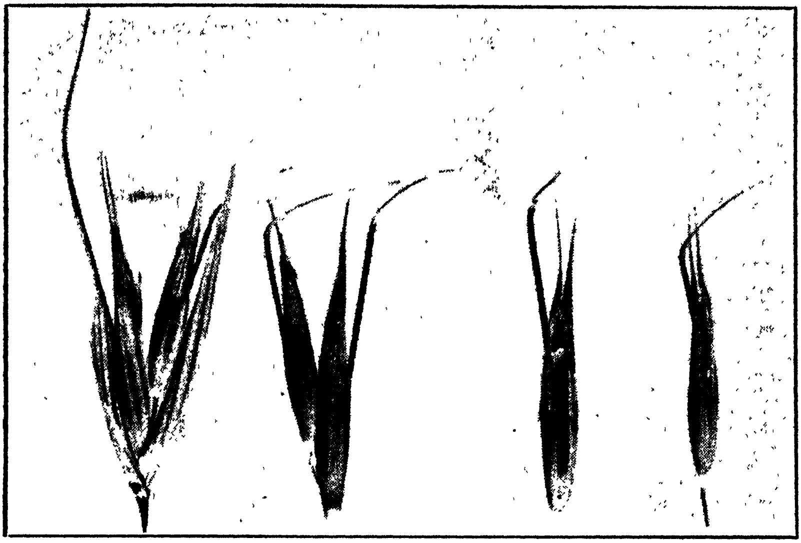

FIG. 7.—Spikelets and florets of *Avena strigosa*. (Enlarged about 2½ times)

Spikelets numerous, 2- to 3-flowered, separating from the supporting rachilla segment (pedicel) by abscission: florets very slender, separating by disarticulation of second (and third) rachilla segment. Glumes 22 to 27 mm long, 5 to 6 mm wide, 7- or 9-veined, light green before

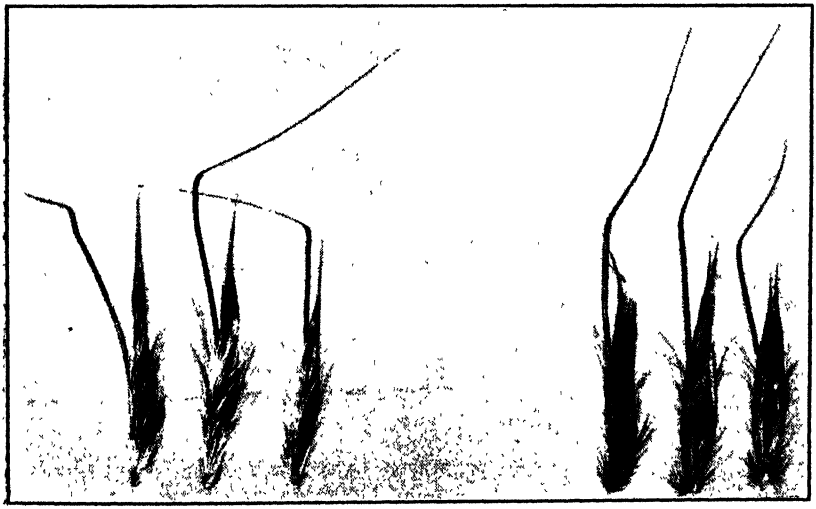

FIG. 8.—Florets of *Avena barbata* (left), florets of *A. wiestii* (right). (Enlarged about 2½ times)

maturity. Lemmas ovate-lanceolate, indurate except toward the apex, grayish brown, villous with white hairs. First lemma 16 to 24 mm long, biaristate, the points 4 to 7 mm long; basal hairs abundant, short, not separate from hairs on lemma; awn always present, 30 to 40 mm long, twisted and geniculate; second lemma 15 to 20 mm long, biaristate, the points 3 to 6 mm long: awn always present, 25 to 35 mm long, twisted and geniculate. Second rachilla segment 3 to 5 mm long, slender, slightly flattened, with an inconspicuous cavity at upper end, pilose.

This oat is similar to *Avena wiestii* Steudel in many spikelet and floret characters. It differs mainly from that species in having a longer and usually a more densely hairy lemma and longer awns. *A. barbata* also can be differentiated from *wiestii* by its more slender and weaker culm and later maturity. (See Figs. 1 and 8.)

CYTOLOGICAL STUDIES

Investigations reported by Kihara (4, 5), Stolze (7), Goulden (2), Huskins (3), and Aase and Powers (1) have established three groups of the species of Avena with regard to chromosome numbers. These are as follows:

Group 1 (haploid number, 7 chromosomes)
Avena brevis Roth, *A. wiestii* Steudel, *A. strigosa* Schreb., and *A. nudibrevis* Vav., [*A. nuda biaristata* (small-seeded naked oat)][4]

Group 2 (haploid number, 14 chromosomes)
Avena barbata Pott.

Group 3 (haploid number, 21 chromosomes)
Avena fatua L., *A. sativa* L., including *A. orientalis* Schreb; *A. nuda* L., large-seeded naked oat; *A. sterilis* L., including *A. ludoviciana* Dur.; and *A. byzantina* C. Koch, including *A. sterilis algeriensis* Trabut.

With the exception of those of *Avena brevis* and *A. strigosa*, the chromosome numbers reported by Nikolaewa (6) differ from those given above. This investigator reported a somatic number of 32 for *A. barbata*, 44 for *A. sterilis*, *A. byzantina*, *A. fatua*, *A. sativa*, and *A. ludoviciana* (a variety of *A. sterilis*), and 48 for *A. nuda inermis*. However, other investigators, who have studied both diploid and haploid tissue, do not agree with the numbers reported by Nikolaewa. More recently, Goulden (2) has reported seven as the haploid chromosome number of *A. barbata*. The material used

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[4] Vavilov (13) recently has applied and used the specific name *Avena nudibrevis* to the "small-seeded naked" oat. He and his coworkers believe it more nearly correct to regard this as a separate species than as a variety of *A. nuda*, viz., *A. nuda biaristata*.

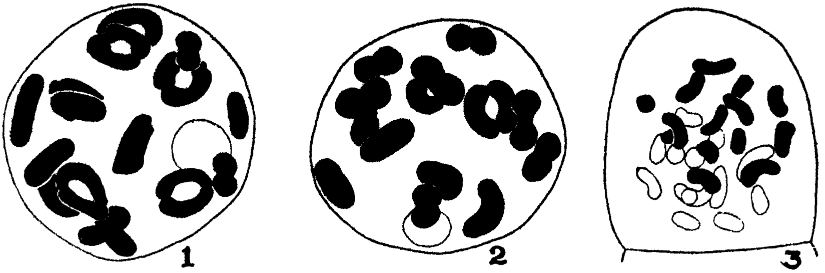

FIG. 9.—C. I. No. 2109 (1) and C. I. No. 2110 (2) show 14 bivalent chromosomes at diakinesis, while C. I. No. 2112 (3) shows 27 chromosomes at the anaphase of the second meiotic division. In the last case one chromosome at the lower plane, the chromosomes of which are shown in outline, is completely obscured and does not appear in the drawing.

by Goulden for this count is *A. wiestii*, as seed of the introduction S. P. I. No. 53626 (see page 811), labeled *A. barbata wiestii*, was furnished him by the Office of Cereal Crops and Diseases of the U. S. Department of Agriculture. The chromosome number reported by Goulden agrees with that reported by Huskins (3) and by Aase and Powers (1) for *A. wiestii*. The similarity of *A. wiestii* and *A. barbata* morphologically has been noted previously in this publication and would account for the confusion.

Seeds of the oat forms C. I. Nos. 2108, 2109, 2110, 2112, and 2113 which were collected in Ethiopia and Eritrea were sent to the Department of Plant Breeding at Cornell University. They were sown in the greenhouse and material obtained for chromosome studies. Preparations were made from root-tips and anthers fixed in Allen's modification of Bouin's fluid and stained with iron-alum-haematoxylin.

The microsporocytes were examined and counts which were made at the stage known as diakinesis indicate a haploid chromosome number of 14. (See Fig. 9.) From counts made in root-tip cells and also at meiosis, the haploid and diploid chromosome numbers of this form are 14 and 28, respectively. These results agree with the belief of Prof. N. I. Vavilov of the Bureau of Applied Botany and Plant Breeding, Leningrad, Russia, who on the receipt of the oat from Doctor Harlan wrote[5] as follows: "The oats forwarded by you are of quite exceptional interest. The variety you send contains, methinks, twenty-eight chromosomes and in this it differs from *Avena brevis* which it reminds outwardly."

In his discussion of the geographical centers where the forms of

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[5] In letter to H. V. Harlan, dated March 7, 1926.

TABLE 1.—*Summary of principal differentiating characters and chromosome numbers of different species of oats.*

Species	Maturity^a	Plant^a height in cm	Spikelet separating from pedicel by	Length (first only) in mm	Lemma Glabrous or hairy	Lemma Length of points in mm	Lemma Color	Awn length in mm	Second rachilla segment Length in mm	Second rachilla segment Glabrous or hairy	Chromosome number
Avena abyssinica . .	Very early	50–90	Fracture	15–22	Glabrous	2–4	White, gray or black	20–30	2–4	Hairy (sometimes only on upper half)	14–28
Avena strigosa	Early to midseason	80–120	Fracture	15–22	Glabrous	5–9 (very distinct)	Gray	20–30	3–5	Hairy only at apex	7–14
Avena wiestii	Early to midseason	80–120	Abscission	14–19	Hairy	2–5	Gray (grayish brown)	15–25	2–3	Hairy throughout	7–14
Avena barbata	Midseason	70–110	Abscission	16–24	Hairy	4–7	Gray (grayish brown)	30–40	3–5	Hairy throughout	14–28

[a] As grown under conditions at Aberdeen, Idaho.

cultivated oats have originated, Vavilov (13) also refers to the oats of Abyssinia as follows: "As an original group appear the cultivated oats and weed-oats of Abyssinia: *A. abyssinica* Hochstetter, *A. schimperi* Körn., *A. hildebranti* Körn., *A. brauni* Körn., which up to now are little explored. Dr. Emme found in these oats 28 (2x) chromosomes."

At this time the authors are not prepared to say definitely if the oat collected by Harlan is identical morphologically with the form or forms mentioned in the above quotation, but in chromosome number it is identical and therefore evidently closely related.

In order to simplify comparison of the four oat forms described in the present paper, a summary of the principal differentiating characters and chromosome numbers is shown in Table 1.

DISCUSSION

An outstanding feature of the chromosome number of the various species of Avena as reported by Kihara (4, 5) and others is that Group 2 is represented by the single species *A. barbata.* The authors believe that the oat form collected by Dr. Harlan in Ethiopia and described in this paper represents a cultivated form of *A. abyssinica*, the origin of which has been discussed by Trabut (8). According to chromosome counts presented here, it represents a second species with a haploid chromosome number of 14. Morphologically, it is similar to *A. strigosa* but evidently is not as closely related to that form as similarity in morphological characters would indicate.

Trabut (8) states that *A. barbata* and *A. wiestii* are similar, morphologically. The writers also have observed this similarity. However, according to the chromosome numbers reported by Kihara (4, 5), Huskins (3), and Aase and Powers (1), these two species belong to different groups. *A. wiestii*, with a haploid number of 7, belongs to Group 1 and *A. barbata*, with a haploid number of 14, to Group 2. Trabut (8) also states that *A. abyssinica* is derived from *A. wiestii*, basing his conclusion on the fact that various transition forms between the two have been found. However, it is evident from observations presented on chromosome number in the form collected by Harlan that these two oat forms can not be considered as being closely related from the cytological standpoint.

On the basis of these facts there apparently is no correlation between the chromosome numbers and the external morphological characters of these oat forms. In so far as origin is concerned, it appears that external morphological characters alone may not show the exact degree of relationshsip.

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A COMPARISON OF SELFED LINES OF CORN AND FIRST GENERATION CROSSES BETWEEN THEM[1]

LOUIS JORGENSON AND H. E. BREWBAKER[2]

INTRODUCTION

As earlv as 1905, Dr. G. H. Shull at Cold Spring Harbor and Dr. E. M. East at the Connecticut Experiment Station started extensive studies to determine the physiology of inheritance in corn. The investigations at the Connecticut Station were continued from 1910 to 1915 by Dr. H. K. Hayes and from 1916 to the present time by Dr. D. F. Jones. Such interest was taken in the early work of Shull and East that about 15 years ago similar studies of the effect of self-fertilization in corn were started by investigators in the United States Department of Agriculture and by several others. At the present time the generally accepted standard method of corn breeding is the selection of the most vigorous and productive self-fertilized lines which are free from abnormalities, and the combination of them in single and double crosses and synthetic varieties.

The studies so far reported are in general agreement to the extent that inbreeding is accompanied by decreased vigor and yielding ability, the degree to which this decrease takes place varying greatly in different selfed lines. It is important to know the extent to which expressions of vigor in the inbred lines are useful indications of the value of these lines as foundation material for crosses and synthetic varieties. As pointed out by Nilsson-Leissner,[3] few experiments have been reported which are pertinent to this particular phase, and the results of these investigations do not agree as to the comparative value of vigorous and weak selfed strains in combination. The present investigation was planned as a companion study to that reported by Nilsson-Leissner. In the present study, inbred lines of the Silver King white dent variety were used, whereas inbred lines of several varieties were used in the other study. It was the purpose of this investigation to determine the relationship

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[3] NILSSON-LEISSNER, GUNNAR. The relation of selfed strains of corn to the F_1 crosses between them. Jour. Amer. Soc. Agron., 19:440–454. 1927.

between certain characters of the inbred lines and the same characters of F_1 crosses between them. The literature cited by Nilsson-Leissner is pertinent to this study, hence the citations and review of literature will not be included in this paper.[4]

MATERIAL AND METHODS

This study was one phase of extensive corn improvement investigations conducted as a regular experiment station project. The material consisted of 10 inbred strains of the dent variety Silver King and the F_1 hybrids between them. The selfed strains were selected from 250 available strains because they were free from any visible abnormalities and were the most vigorous and promising ones so far obtained.

Strains 1, 2, and 3 had been selfed for three years, and the others for four years. All possible combinations of crosses between them were made in the summer of 1925. Sib-pollinations were also made in each of the selfed lines at that time.

The plantings were made at the Waseca branch experiment station. Five kernels were planted per hill. The hills were 3½ feet apart each way, and where there was sufficient seed there were 16 hills per plat. Three replications were made where possible. Each plat consisted of one row, and with the exception of the self- and sib-pollinated strains, each row was separated from the next by a row of normal Silver King. The rows of the corresponding sib-pollinated and self-pollinated strains were planted side by side, the two rows being separated from the next plat by a row of bulk selfed Silver King. Any fractional plats in the inbred lines were planted to bulk selfed, while any fractional plats of the hybrids were planted to normal Silver King. The field was surrounded by a border consisting of four rows of normal Silver King.

When about 6 inches high, the corn was thinned to three plants per hill. Only two- and three-plant hills, completely surrounded by adjacent two- and three-plant hills, were harvested. The first and second ears were harvested separately. Both were used in determining the yield, but only the first ears were measured for the statistical analysis. The moisture content of the ears was reduced to about 2 to 3% before being weighed and measured. Weight was expressed in grams. Length and diameter of ear were measured in centimeters. Diameter was measured as nearly as possible on the same relative position on each ear. All of the first ears were measured where possible. Height of stalks was measured in inches and determined by making several measurements in each plat and taking the average.

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[4] In this connection, the writers wish to correct a statement made by Nilsson-Leissner regarding investigations of Richey and Mayer and of Love and Wentz. Richey and Mayer studied selfed lines and F_1 crosses and correlated the yield of the pistillate parent with that of the F_1 cross, but did not study other characters. Love and Wentz investigated ear characters in relation to yield but did not study selfed lines.

The relative amount of smut was determined as the percentage of the total plants infected. It was classified into percentage of smut above the ear, below the ear, ear smut, and total smut.

COMPARISON OF SELF-POLLINATED AND SIB-POLLINATED LINES

An analysis was made of a number of characters of the self-pollinated lines in relation to the same characters of the sib-pollinated lines in order to determine the approximate degree of homozygosity of the parental selfed lines.

A study was first made to see if there was a correlation between the yields of adjacent plats. The yield of each plat was expressed in percentage of the mean of its line. The correlation between the percentage yields of adjacent plats was determined. The formula used for obtaining the correlation coefficient was $r_{xy} = \frac{\Sigma XY/N - \overline{X}\,\overline{Y}}{G_x\, G_y}$, where X = percentage yield of self-pollinated lines; Y = percentage yield of sib-pollinated lines; $\overline{X}$ and $\overline{Y}$ = their respective means; and G_x and G_y = their respective standard deviations. A correlation coefficient of —0.2944 ±0.1451 was obtained. In veiw of its probable error, the correlation coefficient cannot be considered significant.

For a comparison of the yields, the difference of the mean method for determining the probable error was used. The formula employed was $0.6745\sqrt{\frac{\Sigma(\text{dev.})^2\,(n)}{N(n-1)}}$ where N = total number of plats in the experiment; n = total number of plats in each line; and dev. = the deviation of each plat from the mean of its line. The probable error for a single plat in percentage was divided by $\sqrt{n}$, where n = number of replications, to obtain the probable error of the trial.

TABLE 1.—*Comparison between self- and sib-pollinated lines.*

Line	Sib-pollinated	Self-pollinated	Difference (sib-self)
2	187.6± 6.78	153.4± 8.29	34.2±10.70
3	122.2±10.41	165.2± 7.70	—43.0±12.94
4	189.9± 6.70	152.2± 8.36	37.7±10.70
5	190.8± 6.67	198.6± 6.40	— 7.8± 9.24
6	193.2± 6.58	160.5± 7.92	32.7±10.30
7	160.5± 7.92	161.1± 7.89	— 0.5±11.18
8	140.8±11.06	133.7±11.65	7.1±16.06
9	141.6± 8.98	257.9± 8.54	—116.3±12.39
10	235.0± 9.37	222.0± 5.73	12.0±10.98

In calculating the probable error of a difference the formula used was $\sqrt{a^2+b^2}$, where a and b were the percentage probable errors for the yields of the self- and sib-pollinated lines, respectively. This formula was used as there was little or no correlation between yielding ability of adjacent plats. The comparison of the yielding ability of self- and sib-pollinated lines is given in Table 1.

Four of the self-pollinated lines yielded more than their corresponding sib-pollinated lines. The other selfed lines yielded less than the sib-pollinated ones. The sib-matings were in most, if not in all cases, made by using pollen from a single plant. In this way it would be quite possible to obtain a sib-pollinated line less vigorous than a self-pollinated line. It is probable, however, that the differences obtained between the yield of the self-pollinated and sib-pollinated lines are due largely to the errors of random sampling.

Student's method of comparing two results on a probable error basis was used for the other characters studied. Thirteen characters were studied. The data for these characters in both self- and sib-pollinated lines are presented in Table 2, and the obtained values for Z with the corresponding odds are given in Table 3. In Table 3 the odds indicate that the sib-pollinated lines exceed the self-pollinated lines in case of weight of cobs per hill, height of stalk in inches, percentage of second ears, percentage of moldy ears, number of rows per ear, percentage smut below the ear, and ear smut. In the other six characters considered the odds are in favor of the self-pollinated lines. The lowest odds in favor of the self-pollinated lines are in the case of total smut where Z is lower than any value given in Student's tables and the highest odds obtained are in case of the length of ear where they are 16.4:1. The lowest odds in favor of the sib-pollinated lines are 2.4:1 in the case of percentage of second ears, and the highest odds are 14.6:1 in the case of weight of cobs per hill and percentage ear smut. These differences may be due largely to the errors of random sampling.

Student's method does not show significant odds unless there is a consistent superiority of the sib-pollinated over the self-pollinated or vice versa. It does not show if there are significant differences in individual lines. If large odds are obtained they have a real meaning, but if not, no absolute statement can be made.

A COMPARISON OF F_1 COMBINATIONS

The yields for each of the selfed lines and all F_1 crosses obtained are given in Table 4. The culture numbers are placed above and at the left of the table, and the yield for each cross is placed in the row and column corresponding to the parental culture numbers.

TABLE 2.—*Comparison of self-pollinated and sib-pollinated strains, Student's method.*

No. of strain	Years selfed	Yield per hill in grams	Weight of cobs per hill in grams	Height of stalk in inches	Percentage of second ears	Percentage of suckers	Percentage of moldy ears[a]	Ear characters			Percentage smut			
								Length	Diameter	No. of rows	Above ear	Below ear	Ear	Total
2	3	153.4	46.8	78.0	3.1	6.9	3.3	11.51	4.34	15.17	18.9	9.3	2.2	25.2
2	sib	187.6	37.9	80.0	10.9	13.0	29.9	8.78	4.52	18.20	2.9	3.6	0	6.5
3	3	165.2	34.5	70.0	14.4	7.9	5.0	10.90	4.02	15.40	0.6	5.8	0	6.5
3	sib	122.2	28.1	63.3	33.6	2.4	9.5	10.18	4.12	16.46	0	8.1	0	8.1
4	4	152.2	33.4	56.6	2.7	4.9	12.3	10.92	4.41	12.47	7.1	0	0	7.1
4	sib	189.9	44.1	63.0	0	6.3	12.1	13.27	3.99	12.47	7.0	0	0	7.0
5	4	198.6	40.7	71.3	0.9	5.7	41.2	16.11	3.84	15.41	0	0	0	0
5	sib	190.8	37.3	70.0	0	4.6	66.1	13.80	3.68	15.74	0	0	0	0
6	4	160.5	34.4	84.3	0.8	6.0	47.8	12.68	4.08	14.81	4.4	2.8	0	7.3
6	sib	193.2	37.9	85.3	0	5.6	26.7	13.15	4.13	15.16	3.5	3.6	0	7.2
7	4	161.1	48.0	72.6	8.6	4.9	29.4	12.63	4.13	18.28	2.8	0.7	0	3.5
7	sib	160.5	44.2	71.3	8.6	6.6	45.7	12.18	4.29	18.98	2.1	0	0	2.1
8	4	133.7	24.6	72.3	3.4	9.4	30.6	10.23	4.36	14.92	6.5	0.7	5.3	12.5
8	sib	140.8	26.5	78.0	6.1	4.1	45.3	10.13	4.53	15.29	5.4	2.7	0	8.2
9	4	257.9	44.7	68.0	21.0	10.4	39.7	11.16	4.37	15.08	6.2	0	2.0	8.3
9	sib	141.6	30.5	76.0	11.8	10.9	19.8	9.90	4.11	14.40	1.4	0.7	2.8	4.3
10	4	222.0	56.2	75.0	0	8.2	16.2	12.47	4.62	14.09	5.1	4.4	0.7	10.3
10	sib	235.0	35.0	72.0	0	4.8	15.7	8.60	4.22	13.20	4.8	31.7	0	36.5

[a] The high percentages of moldy ears were due to the very moist conditions in the fall of 1926.

TABLE 3.—*Odds that there are significant differences between certain characters in the self-pollinated lines and the same characters of the sib-pollinated lines as calculated by Student's method.*

	Yield of grain per hill in grams	Weight of cobs per hill in grams	Height of stalk in inches	Percentage of second ears	Percentage of suckers	Percentage of moldy ears	Ear characters Length	Ear characters Diameter	Ear characters No. of rows	Percentage smut Above ear	Percentage smut Below ear	Percentage smut Ear	Percentage smut Total
Z.	0.2037	0.6037	0.2637	0.2278	0.1724	0.3035	0.6039	0.2601	0.4067	0.5521	0.3269	0.6024	0.0366
P.	0.7149	0.9360	0.7564	0.7082	0.6768	0.7896	0.9427	0 7414	0.8547	0.9192	0.8024	0.9360	Very low
Odds O<S[a] . .		14.6:1	3.1:1	2.4:1		3.7:1			5.8:1		4:1	14.6:1	
Odds O>S					2:1		16.4:1	2.8:1		11.3:1			Very small

[a] O = Sib-pollinated.
S = Self-pollinated.

TABLE 4.—*Yield of selfed lines and F_1 hybrids between them.*

No. of selfed lines	4	2	6	7	3	8	5	1	10	9	Average yield of crosses in grams	Yield of selfed line in grams
4	——	400.2	374.8	360.8	346.4	372.0	224.8	413.6	374.6	343.6	356.7	152.2
2	400.2	——	396.7	401.5	287.7	487.1	392.6	404.5	379.6	398.2	393.5	153.4
6	374.8	396.7	——	397.8	380 7	369 0	333.1	——	395.4	422.4	384.2	160.5
7	360.8	401.5	397.8	——	298.4	327.2	408.9	424.2	——	——	374.1	161.1
3	346.4	287.7	380.7	298.4	——	——	353.4	391.4	——	344 7	343.2	165.2
8	372.0	487.1	369.0	327.2	——	——	323.4	375.8	382.5	369.6	375.8	171.8
5	224.8	392.6	333.1	408.9	353.4	323.4	——	340.8	388.0	——	345.6	198.6
1	413.6	404.5	——	424.2	391.4	375.8	340.8	——	——	——	391.7	214.4
10	374.6	379.6	395.4	——	——	382.5	388.0	——	——	402.5	387.1	222.0
9	343.6	392.2	422.4	——	344.7	369.6	——	——	402 5	——	379.1	270.7

The average yield of all hybrids in which any one selfed line enters and the yield of the corresponding selfed line are placed in the next to the last and the last columns, respectively.

A study of the table shows that there are low as well as high yielders among the hybrids of each of the selfed lines. On the basis of the average yield of the F_1 hybrids in which they have been used as parents, some selfed lines appear distinctly superior to others as parents of crosses. For instance, hybrids of lines 1, 2, 6, 9, and 10 are generally good yielders. Twenty of the 37 hybrids in the test yielded more than 375 grams per hill; and of these 20 better yielding hybrids all except 1 have one or both of these lines as parents. On the other hand, line 5 is a fairly good yielder, but poor in combination, for five out of a total of eight hybrids in which this line was used proved to be low in yielding ability.

Using the average yield of all the hybrids in which any single selfed line entered as a measure of its combining ability with other lines, the six with the highest yielding hybrids are lines 2, 1, 10, 6, 9, and 8, in the order given. Four of these six are among the five highest yielding selfed lines and two are among the five lowest yielding selfed lines

In general, then, it can be said that the better-yielding selfed lines are somewhat more satisfactory for the production of F_1 hybrids than the lower-yielding selfed lines, although there are certain exceptions

Having obtained the comparative yielding ability of the F_1 hybrids for the various possible combinations of selfed lines, it should be possible to predict with a fair degree of accuracy which lines would combine well in double crosses and synthetic varieties. Taking as an example the F_1 hybrids which yielded 375 grams or over per hill, the data available show that lines 2, 6, 9, and 10 combine well in all possible crosses with each other. It is reasonable to suppose, then, that they should combine well in a double cross. By including all hybrids yielding 350 grams or more per hill, several good double cross combinations can be found Three such combinations are 2, 8, 9, and 10; 1, 2, 4, and 7; and 1, 2, 4, and 6. Similarly, it should be possible to produce a good synthetic variety from lines 2, 6, 8, 9, and 10 as each of them combines well with any of the others.

CORRELATIONS BETWEEN CERTAIN CHARACTERS OF THE SELFED LINES AND THE SAME CHARACTERS OF THE F_1 HYBRIDS

Correlations between a number of characters of the selfed lines and the same characters of the F_1 hybrids between them were calculated as a measure of the extent to which such characters exhibited by the selfed lines are expressed in the first hybrid generation. All data used are averages of the three series. The average of the two parental lines was correlated with the F_1. The formula used for calculating these correlations was similar to the one used in studying the correlation between adjacent plats.

TABLE 5.—*Coefficients of correlation between the average of certain characters of the two parental selfed lines and the same characters of the F_1 hybrids.*

Characters correlated	Coefficient of correlation
Yield (grams per hill)	0.5000±0.0771
Length of ear	0.5805±0.0763
Diameter of ear	0.6305±0.0620
Number of kernel rows	0.7894±0.0388
Height of stalk	0.4759±0.0796
Date of silking	0.2872±0.0944
Date of tasseling	0.0977±0.1019
Percentage moldy ears	0.0206±0.0985
Weight of seed	0.3904±0.0953
Percentage second ears	0.1774±0.0996
Weight of cobs per hill (grams)	0.2269±0.0976
Percentage smut below ear	0.3116±0.0838
Percentage smut above ear	0.1219±0.1013
Percentage ear smut	0.0068±0.1028
Percentage total smut	0.1659±0.1000

Positive correlations were obtained in all cases. The correlations for the characters yield, length of ear, diameter of ear, number of kernel rows, height of stalk, and weight of seed of the parents and offspring are high and significant. These six characters are all expressions of vigor with the possible exception of number of kernel rows.

The frequency distribution of two of the characters studied, and their regression lines, are given in the following tables. These are the regressions of the yield of the F_1 hybrids on the yield of the parents and the length of ear of the F_1 hybrids on length of ear of the parents. They were chosen because yield is the most important character dealt with and length of ear is one of the important expressions of vigor which is directly correlated with yield. Blakeman's test[5] for the linearity of regression was determined for these two frequency distributions (Tables 6 and 7). In both cases values of less than 1.5 were obtained which indicate that the regression was approximately linear.

[5] BLAKEMAN, JOHN. On tests for linearity of regression in frequency distribution. Biometrika, 4:332–350. 1905.

TABLE 6.—*Regression of yield of grain per hill of hybrids on yield of grain per hill of parents.*

Parents	F₁ hybrids 1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
7										1					1
6								1	1		2				4
5							1		2			1			4
4	1						1	2	4	4	1				13
3					2	2	1	3	2	3	1			1	15
2		1		1		1	1	2							6
1															0
	1	1	0	1	2	3	4	8	9	8	4	1	0	1	43

TABLE 7.—*Regression of length of ear of hybrids on length of ear of parents.*

Parents	F₁ hybrids 1	2	3	4	5	6	7	8	9	10	11	Total
9								1				1
8	1				1			1				3
7										2		2
6						1	2	2	1	1		7
5						2		1				3
4			1		2	3	2	1	2	1		12
3			2	2	3		2					9
2							1	1			1	3
1						3						3
	1	0	3	2	6	9	7	7	3	4	1	43

MULTIPLE CORRELATIONS

Another method of determining the influence of the parental lines upon the F₁ hybrids is by calculating a multiple correlation between some such character as yield of the F₁ hybrids and important characters of vigor of the parental selfed lines. The parental characters chosen were length of ear, diameter of ear, number of kernel rows, height of plant, and yield. This multiple correlation expresses the degree to which the dependent variable is correlated with the other factors considered.

The multiple correlation was calculated from the simple product moment correlation coefficients and from the regression values by the following formula:

$$R^2_{a.bcdef} = (b_{ab.cdef}\, r_{ab}) + (b_{ac.bdef}\, r_{ac}) + (b_{ad.cbef}\, r_{ad}) + (b_{ae.bcdf}\, r_{ae}) + b(_{af.bcde}\, r_{af})$$

$$R = \sqrt{R^2_{a.bcdef}}$$

The simple product moment correlations calculated for this purpose are given in Table 8.

TABLE 8.—*Simple product moment correlations.*

	Characters correlated	Correlation coefficient
$r_{1,2}$	Yield of grain of hybrids with length of ear of parents	—0.0190±0.1028
$r_{1,3}$	Yield of grain of hybrids with diameter of ear of parents	0.1608±0.1447
$r_{1,4}$	Yield of grain of hybrids with number of rows of parents	—0.0146±0.1028
$r_{1,5}$	Yield of grain of hybrids with height of plant of parents	0.2365±0.0971
$r_{1,6}$	Yield of grain of hybrids with yield of grain of parents	0.5000±0.0771
$r_{2,3}$	Length of ear of parents with diameter of ear of parents	—0.3599±0.1631
$r_{2,4}$	Length of ear of parents with number of rows of parents	0.2635±0.0957
$r_{2,5}$	Length of ear of parents with height of plants of parents	0.2631±0.0957
$r_{2,6}$	Length of ear of parents with yield of grain of parents	0.0733±0.1022
$r_{3,4}$	Diameter of ear of parents with number of rows of parents	0.0268±0.1027
$r_{3,5}$	Diameter of ear of parents with height of plant of parents	—0.1018±0.1017
$r_{3,6}$	Diameter of ear of parents with yield of grain of parents	0.2250±0.0976
$r_{4,5}$	Number of rows of parents with height of plant of parents	0.3824±0.0878
$r_{4,6}$	Number of rows of parents with yield of grain of parents	—0.0336±0.1027
$r_{5,6}$	Height of plant of parents with yield of grain of parents	—0.1169±0.1014

Some of the simple product moment correlations are not exactly as expected. For instance, no significant correlation was obtained between average length of ear of the parents and yield of the F_1 hybrids. Neither was a significant correlation obtained between average length of ear of the parents and yield of the parents Fairly high correlation coefficients for these relationships were obtained by other investigators.[6]

Positive and significant correlations were obtained between yield of grain of the hybrids and the same character of the parents, and also between number of kernel rows per ear and height of plant of the parents.

The multiple correlation (R) obtained was 0.6074. This was substituted in the formula 100 $(1-\sqrt{1-R^2})$ which gave a direct measure of the degree to which the variation in yield of F_1 hybrids is a function of the parental characters concerned. The results showed that about 20% of the variability of the yield of the F_1 hybrids was accounted for by the variation of the parental factors considered

DISCUSSION

It is of genetic interest to know that crosses between two low-yielding selfed lines of corn sometimes produce F_1 hybrids with high-yielding ability, that crosses between low- and high-yielding strains often produce high-yielding hybrids, and that occasionally low-yielding hybrids are produced by crossing two high-yielding selfed lines. Two relatively low-yielding selfed lines, 2 and 6, were consistent in producing high-yielding hybrids when crossed with other selfed lines. It is known that in many cases vigor and yield are limited by a single genetic factor, conditioning such recessive characters as golden plant, dwarfed, and slashed, when in the homozygous condition. When these genetic factors are carried in the heterozygous condition, their effect is not noticeable. It is possible that these two low-yielding selfed lines carry the homozygous recessive for some such deleterious but less obvious character. When crossed with the other selfed lines, the hybrids carry these factors in the heterozygous condition and are vigorous and productive. It should be remembered that all of the 10 selfed lines used in this study were selected on the basis of vigor. In general, even though the parental strains were selected for high-yielding ability, there was a positive correlation between the average yielding ability of the parents and that of the F_1 hybrids.

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[6] HAYES, H. K. Present-day problems of corn breeding. Jour. Amer. Soc. Agron., 18:344–363. 1926.

Nilsson-Leissner, who studied the combined data of F_1 crosses between selfed lines obtained from the same and from different varieties, found similar results. The results indicate the great importance of continued and extensive studies made for the purpose of obtaining or producing the most vigorous selfed lines possible.

SUMMARY AND CONCLUSIONS

1. An investigation has been made of 10 selfed lines of maize within a variety and the F_1 hybrids between them. These lines had been selfed from three to four generations but appeared to be relatively homozygous on the basis of a comparison of the selfed and sib-pollinated lines.

2. Both high and low yielders were obtained among the hybrids of each of the selfed lines, but some are distinctly superior as parents of crosses.

3. Positive and significant correlations were obtained between the following characters of the parents and the same characters of the F_1 hybrids. All of these characters, with the possible exception of number of kernel rows per ear, are expressions of vigor. The more important correlation coefficients are as follows

Characters expressing vigor	Coefficient of correlation
Yield (grams per hill)	0.5000±0.0771
Length of ear	0.5805±0.0763
Diameter of ear	0.6305±0.0620
Number of kernel rows per ear	0.7894±0.0388
Height of stalk	0.4759±0.0796
Weight of seed	0.3904±0.0953

4. A multiple correlation was calculated with yield of the F_1 as the dependent variable and the characters of length of ear, diameter

of ear, number of kernel rows per ear, height of plants, and yield in grams per hill of the parents as the independent factors. The correlation was 0.6074. These characters of the parental lines were found to account for about 20% of the variability of yield of the F_1 hybrids.

5. It is concluded that the selection of the most vigorous selfed lines for the production of single and double crosses or synthetic varieties is the proper procedure for practical corn breeding. All combinations of selfed lines may be studied in order to determine which ones will perform best in double crosses or synthetic varieties.

INHERITANCE OF AWNEDNESS IN RICE[1]

JENKIN W. JONES[2]

INTRODUCTION

The rice varieties now grown commercially in California consist of awnless and of partly awned varieties. Fully awned varieties are no longer grown commercially in California. In fully awned varieties all spikelets are awned, but the awns may vary on the same panicle from 1 mm to 6 cm or more in length. In partly awned varieties both awned and awnless spikelets are present on the same panicle, while in true awnless varieties the awns are entirely lacking. In California. good examples of each of these three groups are the Butte, Caloro, and Colusa varieties, respectively.

Jones (3)[3] has observed that some apparently awnless rice varieties produce awns on the panicles of secondary or branch culms. These branch culms often are produced by plants that are allowed to stand in the water unharvested after the panicles of the primary culm have matured This is a good illustration of a plant of identical genetic constitution producing a different end result under slightly different environmental conditions. Late in the growing season, the branch culm panicles, which are produced after the primary panicles have matured, must develop under lower temperatures than those which prevailed when the main-culm panicles were produced. The humidity also is higher late in the season, and the days are shorter. Then, too, the soil solution late in the season probably is quite deficient in certain plant food elements, and this may be favorable to the production of awns. Gericke (1) reports that he found this to be true in the case of awns in Sonora wheat.

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[1] Contribution from the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, in cooperation with the California Agricultural Experiment Station. Received for publication May 26, 1927.

[2] Associate Agronomist and Superintendent of the Biggs Rice Field Station, Biggs, Calif. The writer desires to thank Mr. C. F. Dunshee and Mr. W. D. Comstock for taking the notes on the F_2 population.

[3] Reference by number is to "Literature Cited," p. 839.

The fact that some apparently awnless rices produce panicles on branch culms in which some spikelets are awned indicates that a good deal of care must be used in selecting the parents for a study of the inheritance of awns. If such a variety is used in a cross with an awned variety to provide material for a study of the inheritance of awns, the results probably will be difficult to analyze, and erroneous conclusions are very likely to be drawn.

The awn is an important character in the classification of rice varieties. Awned rices also as a rule do not shatter readily, and they are seldom attacked by birds. The awns, however, make such varieties rather disagreeable to handle, both in the field and in the rice mills.

The inheritance of awnedness in rice has been studied by Van der Stok according to McKerral (4), and also by Mendiola (5). The latter has summarized Van der Stok's and McKerral's findings as follows:

"(1) Beardedness is dominant over beardlessness when the beard is 'highly developed,' that is, probably when the plant is long bearded; (2) beardedness in case No. 1 is not completely dominant; (3) beardedness is not dominant over beardlessness when the bearded plant is short bearded; and (4) in case of No. 2, it is suspected by McKerral that more than one factor is involved in the production of beardedness."

Mendiola (5), in a study of the inheritance of awnedness in rice in natural crosses, found that awnedness was partially dominant over awnlessness, and that in the varieties studied one or possibly two factors were involved in the production of awns. Hoshino (2) reports that in rice awnedness is dominant to awnlessness in F_1, a fact which is well known in Japan.

In 1923, at the Biggs Rice Field Station, Biggs, Calif., the writer crossed the Butte and Colusa varieties, and in the following pages are reported the results of a study of the inheritance of awnedness in the F_1, F_2, and F_3 generations. Data also are presented on the inheritance of awnedness in the F_1 and F_2 generations of the cross Colusa x Italian Red.

Butte is a midseason fully awned variety, that is, all spikelets are awned, the awns varying in length from 1 mm to 6 cm. Italian Red is an early maturing partly awned variety. Colusa is awnless

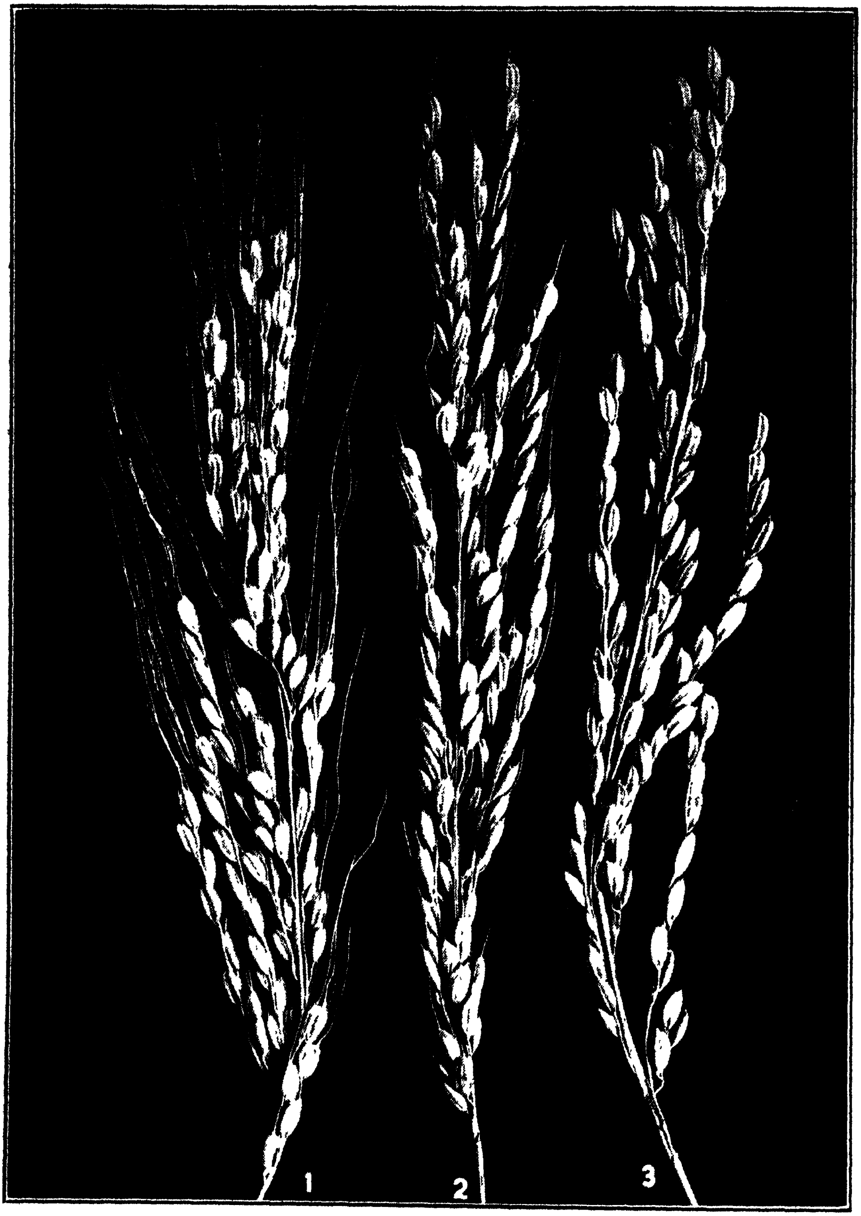

FIG. 1.—Average length of awns in (1) Butte; (2) F_1 hybrid; and (3) Colusa.

under all conditions, as far as we have found, and therefore is a suitable variety for use as one parent in a study of the inheritance of awnedness.

BUTTE X COLUSA CROSS

F_1 GENERATION

The F_1 seed was sown in paper pots on May 9, 1924, and was irrigated the same day. The seedlings emerged between May 18 and 21, and eight F_1 plants were grown to maturity. These F_1 plants were partly awned. The awns ranged in length from 1 mm to 5 cm. While some spikelets on each panicle were awnless, most of them were awned. Awnedness therefore was partially dominant in F_1 plants, as each panicle contained many more awned than awnless spikelets. However, the awns of the F_1 were shorter than those of the Butte parent. (See Fig. 1.)

F_2 GENERATION

In 1925, five F_2 families were grown in rod rows spaced 2 feet apart. In all, 837 F_2 plants were grown to maturity. The panicles of each plant were harvested separately and placed in manila envelopes. Determinations of the number of awned plants were made in the laboratory.

For convenience in classification of the F_2 plants they were placed in four groups, namely, A, B, C, and D. Group A consisted of plants with awns varying in length from 1 mm to 6 cm or more. This group included plants that were fully awned like the female parent (Butte) and also plants like the F_1 hybrid, that is, with most of the spikelets awned but with awns shorter than those of the female parent, and a few awnless spikelets on each panicle. Group B consisted of plants with awned and awnless spikelets about equal in numbers on the same panicles, the awns varying from 1 mm to 1 cm or more in length and being present on spikelets in various parts of the panicles. Group C consisted of plants with awned and awnless spikelets on the same panicle, but most of the spikelets were awnless. The awns on these plants varied from 1 to 5 mm in length and were present as a rule only on one or a few of the upper spikelets on the panicles. Group D consisted of awnless plants. In the F_2 population there were plants present with awns ranging from 1 mm in length in Group C to 6 cm or more in length in Group A, and there were all gradations in awn length between these two extremes. The Groups A, B, C, and D were intended to correspond with components of a suspected dihybrid 9: 3 : 3 . 1 ratio, the large Group A being almost fully awned, Groups B and C partly awned but in decreasing proportions of awns, and Group D recessive awnless.

In Table 1 is given the number of F_2 plants in Groups A, B, C, and D, respectively, as determined by the laboratory counts. It is observed that the A and D groups are in close agreement with the calculated numbers in the 9 and 1 parts of a 9 : 3 : 3 : 1 ratio. In fact, the observed and calculated numbers are almost identical for the D group. The deviations, however, from the calculated ratio for the B and C groups are very large, and such deviations are most certainly significant. There are far too many plants in Group B and too few in Group C. This probably is due to errors in the classification of the partly awned F_2 plants placed in these groups. The large variation in the length of awns in the partly awned plants makes a proper separation of them into two groups practically impossible. If, however, Groups B and C are combined, the calculated dihybrid ratio becomes 9 : 6 : 1, and the expected and observed numbers of plants agree very well, as is shown also in Table 1. The deviations from the calculated ratio for each group now are small and apparently are not significant.

F_3 GENERATION

Forty F_3 families, including plants from Groups A, B, C, and D, were grown in 1926. Nine F_3 families were from Group A, 15 from Group B, 7 from Group C, and 9 from Group D. In F_3 three families from Group A bred true for the fully awned character, while three families segregated for all awn types in Groups A, B, and C, but produced no awnless D plants. The other three families segregated for all degrees of awnedness in the four groups.

Three F_3 families from Group B and 1 from Group C bred true for the B and C awn types of awnedness, respectively, and 12 families from Group B and 6 from Group C segregated for B and C awn types and awnless D type, respectively.

Eight F_3 families from Group D bred true for awnlessness, and one family segregated for C type of awns and for D awnlessness. This family apparently was incorrectly classified in F_2.

TABLE 1.—*Segregation of F_2 plants of the Butte x Colusa cross for awnedness when grown at Biggs, Calif., in 1925.*

Awnedness group	Number of F_2 plants			
	Observed	Expected	Deviation from expected	Probable error
	On the basis of a ratio of 9:3::3:1[a]			
A, awned.......	458	470.79	— 12.79	9.68
B, partly awned..	273	156.93	+116.07	7.62
C, partly awned..	54	156.93	—102.93	7.62
D, awnless	52	52.31	— 0.31	4.72
	On the basis of a ratio of 9:6:1[b]			
A, awned.......	458	470.79	— 12.79	9.68
B and C, partly awned.........	327	313.86	+ 13.14	9.45
D, awnless.......	52	52.31	— 0.31	4.72

[a] 42, very large, an extremely poor fit.

[b] *P* 0.65, a good fit.

The awnedness of F_3 plants from three F_2 group A plants is shown in Table 2. Unfortunately, in the segregating F_3 families from Group A the fully awned (A) and partly awned (B and C) plants were not counted separately. Therefore, in Table 2 the fully awned and partly awned plants are grouped together as awned, and the ratio becomes 15: 1, and not 9: 6: 1, as it would have been had the awned and partly awned plants been counted separately.

The population of each family shown in Table 2 is very small, but even though small the deviations from the numbers expected in a 15:1 ratio (really 9: 6: 1) likewise are small and apparently not significant. These data confirm the two-factor hypothesis, and while the calculated 15: 1 ratio used here suggests the duplicate factor explanation, the objections are that awned plants and some partly awned with awns of various lengths were observed in these segregating families. Such types evidently are due to independent segregation of two factors which do not give duplicate or identical results. Other evidence in this connection is that some Group A families bred true for the fully awned condition, while others segregated and produced A, B, and C or A, B, C, and D types. Some Group B and C families bred true as partly awned, or segregated in the ratio of three partly awned plants to one awnless plant. If the awn types A, B, and C, however, were due to duplicate factors, some B and C families should segregate in the same way as the A families, and this did not occur. Therefore, the theory of duplicate factors does not fit the results, but that of two independent factors does.

TABLE 2.—*Segregation for awnedness in the F_3 progeny of three F_2 plants from fully awned Group A of the Butte x Colusa cross when grown at Biggs, Calif., in 1926.*

F_2 plant No.	Number of F_3 plants				
	Awned and partly awned	Awnless			
		Observed	Expected on 15:1 ratio	Deviation	Probable error
11	31	4	2.1875	+1.8125	0.97
20	50	4	3.3750	+0.6250	1.20
32	50	7	3.5625	+3.4375	1.23
Total	131	15	9.1250	+5.8750	1.97

The segregation for awnedness of F_3 progeny of 12 F_2 partly awned Group B plants is shown in Table 3. The population for each of the families represented in Table 3 is small, yet in no case is the deviation from the calculated 3: 1 ratio equal to twice the probable error. The total deviation for the 12 families was only 0.75 of a plant with a probable error of ±7.80. This is an excellent agreement with the expected monohybrid ratio of three plants partly awned to one awnless.

The segregation for awnedness of the F$_3$ progeny of seven F$_2$ partly awned Group C plants is shown in Table 4. The number of plants in each family reported in Table 4 is small. However, in only one family is the deviation from the number expected in the calculated 3: 1 ratio equal to more than three times the probable error. All other deviations are much less than three times the probable error and therefore are not significant. This indicates that a one-factor difference exists between the partly awned and awnless plants in Group C.

TABLE 3.—*Segregation for awnedness in F$_3$ progeny of 12 plants from partly awned group B of the Butte x Colusa cross when grown at Biggs, Calif., in 1926.*

	Number of F$_3$ plants			
F$_2$ plant No.		Awnless		
	Partly awned	Observed	Expected on 3:1 ratio	Deviation and probable error
7	46	20	16.50	+3.50±2.37
10	42	11	13.25	—2.25±2.13
13	51	15	16.50	—1.50±2.37
14	50	17	16.75	+0.25±2.39
16	39	17	14.00	+3.00±2.19
16	60	15	18.75	—3.75±2.53
16	40	15	13.75	+1.25±2.17
17	25	5	7.50	—2.50±1.60
22	31	12	10.75	+1.25±1.92
26	42	14	14.00	----
33	55	18	18.25	—0.25±2.50
35	53	20	18.25	+1.75±2.50
Total	534	179	178.25	+0.75±7.80

TABLE 4.—*The segregation for awnedness of the F$_3$ progeny of seven F$_2$ partly awned Group C plants of the Butte x Colusa cross when grown at Biggs, Calif., in 1926.*

	Number of F$_3$ plants			
F$_2$ plant No.		Awnless		
	Partly awned	Observed	Expected on 3:1 ratio	Deviation and probable error
1	41	16	14.25	+1.75±2.20
3	30	20	12.50	+7.50±2.07
14	46	15	15.25	—0.25±2.28
20	42	18	15.00	+3.00±2.26
21	35	11	11.50	—0.50±1.98
28	31	18	12.25	+5.75±2.04
36	36	15	12.75	+2.25±2.09
Total	261	113	93.5	+19.5±5.65

As it was impossible to separate correctly the partly awned plants (Groups B and C) in the F$_2$ population, it would be logical to consider these two groups as one unit in F$_3$ segregations. If this is done, the 19 segregating B and C F_3 families of Tables 3 and 4 gave 795 partly awned plants to 292 awnless. These numbers are in close agreement with the numbers in the expected 3:1 ratio. The deviation from the expected numbers in this ratio is 20.25 plants with a probable error of ±9.63, which indicates a close fit.

DISCUSSION

If it is assumed that in the fully awned variety, Butte awnedness is due to the dominant factors AABB, and that in the awnless variety Colusa awnlessness is due to the recessive factors aabb, then the F_1 plants would be of the genetic constitution AaBb. Each panicle of these F_1 plants had more awned than awnless spikelets, so awns are partially dominant. It appears, however, that only plants of the genetic constitution AABB are fully awned.

Selfed F_1 plants of the genetic constitution AaBb should produce F_2 plants of the following phenotypes and genotypic constitution, and these correspond to the groups A, B, C, and D as used in this paper.

F_2 phenotypes and breeding behavior in F_3.

Group A; awned
1 AABB Breeding true.
2 AABb Segregating for 3 long and mid-length awns to
2 AaBB 1 short.
4 AaBb Segregating as in F_2 in 9: 6: 1 ratio.
—
9

Groups B and C; partly awned
1 AAbb Breeding true.
1 aaBB
2 Aabb Segregating for 3 partly awned to 1 awnless.
2 aabb
—
6

Group D; awnless
1 aabb Breeding true

In F_3 progeny from Group A there should be plants of the genetic constitution AABB that bred true for the fully awned condition, and three such families were found. There also should be plants of the genetic constitution AABb and AaBB that segregated in the ratio of three awned to one partly awned plants, and three families were observed to segregate for all awn types, but, unfortunately, the number of plants in each group was not determined separately. However, there is little doubt but that they were derived from plants *of these genetic constitutions. There also should be plants of the genetic constitution AaBb which would segregate just as the selfed* F_1 *plants did, and three families were found that segregated in this manner.*

In the F_3 from Groups B and C there should be plants of the genetic constitution AAbb and aaBB which bred true, and four such families were found. Also, there should be plants of the genetic constitution Aabb and aaBb which segregate in F_3, giving plants in the ratio of three partly awned to one awnless, and 19 such families were grown.

In the F_3 from Group D there should be only plants of the genetic constitution aabb, all of which bred true for awnlessness, and eight such families were grown. One family, however, segregated for partly awned and awnless plants and no doubt belonged in Group C.

COLUSA x ITALIAN RED CROSS

The cross of Colusa and Italian Red was made by the writer in the fall of 1924. The F_1 seed was sown in paper pots on May 13, 1925. The seedlings emerged from May 20 to 24, inclusive, and were transplanted to the nursery on May 26. Three F_1 plants, all of which were partly awned, were grown to maturity.

F_2 GENERATION

On May 2, 1926, part of the seed from two F_1 plants was sown in the nursery in 15 rod rows spaced 2 feet apart. The seed was spaced about 6 inches apart in the rows. The segregation for awns in F_2 resulted in 361 partly awned plants to 153 awnless. The deviation from the numbers expected in a 3:1 ratio is 24.5 plants with a probable error of ±6.62, which indicates that possibly other factors or conditions are influencing the results.

SUMMARY

1. The crosses Butte x Colusa and Colusa x Italian Red were used in the study of the inheritance of awnedness reported in this paper. Butte is a fully awned variety, while Italian Red is partly awned, and Colusa is a variety awnless under all conditions.

2. Awnedness is partially dominant to awnlessness in F_1 and the F_2 of the Butte x Colusa cross segregated in the phenotypic ratio of nine awned to six partly awned to one awnless plants. The F_2 of the Colusa x Italian Red cross segregated in the phenotypic ratio of about three partly awned plants to one awnless plant.

3. The data presented in this paper indicate that two independently inherited genetic factors are involved in the inheritance of awnedness in the Butte x Colusa cross and one genetic factor in the Colusa x Italian Red cross.

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ROOT DEVELOPMENT OF COTTON ON CECIL SANDY LOAM DURING 1926[1]

GILBEART H. COLLINGS AND J. D. WARNER[2]

Considerable work has been reported from time to time on the root development of most of the major field crops of the United States with the exception of cotton. This omission was recently emphasized upon the publication of Weaver's book on *Root Development of Field Crops* in which a very thorough treatment of the root systems of the major field crops of the United States, with the exception of cotton, was undertaken.

Very little is known concerning the development of the root system of cotton under varying soil conditions. As early as 1889, Whitney (4)[3] of the South Carolina Experiment Station reported having traced the tap root of a cotton plant in light sandy soil at Columbia, South Carolina, to a depth of 3 feet without coming to the end. However, on a heavy loam he found that the tap roots of cotton grew to a depth of only 9 inches, although the secondary roots penetrated the soil laterally from 30 to 36 inches. Balls (1), working in Egypt under irrigation conditions, was able to trace a cotton root to 7¼ feet below the surface. King (2), also working under irrigation condition but in the Southwest, has reported tracing a cotton root to a depth of 10 feet, 8 inches. However, little attention has been focused on the lateral extension of cotton roots.

Weaver (3) has shown that the development of roots of field crops is greatly influenced by such environmental factors as soil type, height of the water table, and especially fertilization. As the cotton crop receives more fertilizer than any other American crop, it is surprising that more attention has not been paid to the influence of fertilizers on the development of cotton roots.

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[1] Contribution from the Division of Agronomy, Clemson Agricultural College and South Carolina Experiment Station, Clemson College, S. C. Received for publication May 31, 1927.

[2] Associate Professor of Agronomy and Assistant Agronomist, respectively.

[3] Reference by number is to "Literature Cited," p. 842.

In the spring of 1926 the writers undertook to study the root systems of cotton plants which were growing under normal field conditions on the farm of the South Carolina Agricultural Experiment Station. The type of soil upon which the cotton was grown was Cecil sandy loam. As this soil type predominates in the Piedmont Province of the Southeast, the results secured in this study should be applicable to a large area of the cotton belt.

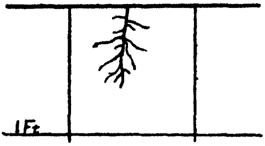

FIG. 1.—Root system of cotton 23 days old. Height of average plant 3 inches.

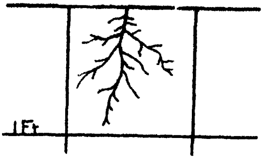

FIG. 2.—Root system of cotton 33 days old. Height of average plant 6 inches.

The cotton studied was of the Cleveland variety and was planted on May 14 in 3-foot rows and 6 to 12 inches in the drill. The spring and summer of 1926 were exceedingly dry and it is very probable that this dry period had some influence on the development of the root systems. In Table 1 is given the rainfall for the five summer months of 1926 compared with a 32-year average for the same months.

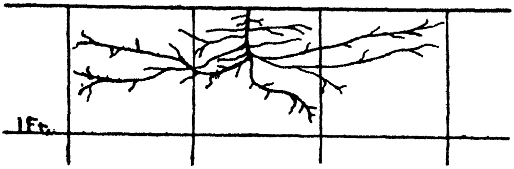

FIG. 3.—Root system of cotton 73 days old. Height of average plant 18 inches.

TABLE 1.—*Rainfall for summer months at Clemson College, S. C.*

Month	1926	Average, 1892–1924
May	0.33	3.94
June	4.45	4.85
July	3.79	5.27
August	3.40	5.00
September	2.96	4.10

At intervals throughout the growing season a number of root systems of representative plants were removed from the soil. The technic of removal was as follows. After selecting a section of a row where all the plants appeared to have developed normally, a ditch was dug parallel to the row. Beginning on the ditch side the soil around each plant was carefully removed with a geologist's sampling hammer in such a way that each root encountered was traced from end to end. As the work progressed, the roots were measured and the root system was drawn to scale showing the natural arrangement in a vertical plane.

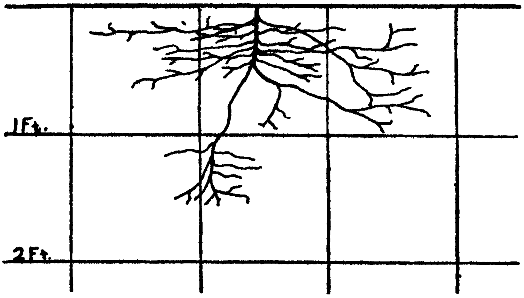

FIG. 4.—Root system of cotton 97 days old. Height of average plant 24 inches.

It was observed that the development of the root systems of plants of the same age and size was very uniform. In Figs. 1 to 5, inclusive, are given the drawings of representative root systems at the various ages studied.

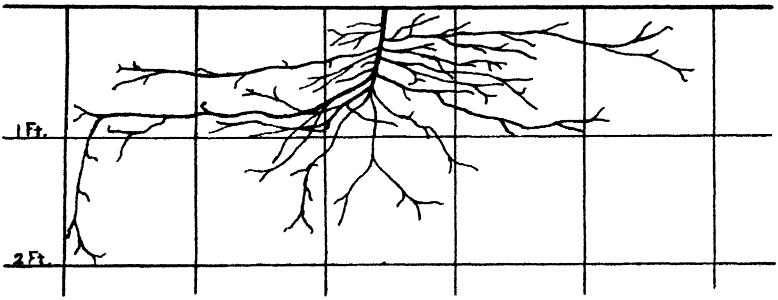

FIG. 5.—Root system of cotton 115 days old. Height of average plant 59 inches.

An interesting observation that was noted throughout the study was the small extent to which the soil was occupied by roots. This observation is borne out by the accompanying drawings. Even with mature plants it was apparent that the soil could have accommodated, so far as unoccupied soil was concerned, many more plants per acre.

The greater portion of the development of the root system was confined to the surface 8 inches of soil, although many roots of mature plants reached a depth of a foot. This observation is in line with the observations of Whitney (4) on cotton and the commonly held views of soil men regarding the root extension of most field crops, but contrary to the observations of Weaver (3) who has shown that most field crops have an extensive root development below a foot from the surface.

The greatest depth reached by any root was 2 feet. This root was a secondary root and is shown in Fig. 5. The approximate average depth of all root systems of mature plants studied was 20 inches.

It was observed, as shown in Fig. 5, that very few roots of mature plants extended in a lateral direction over 2 feet from the center of the plant. At first it was believed that cultivation had probably destroyed many of those roots which had ventured out into the middles. However, further study showed the same condition existing within the row itself.

Six hundred pounds per acre of a 10–4–2 fertilizer had been applied in the drill 3 inches below the surface before the cotton was planted. In no case was it observed that a greater development of the root system had taken place in the neighborhood of the fertilizer. As the soil was excavated, it was found that the fertilizer had not been thoroughly mixed with the soil and that very little root development had taken place above the fertilizer. It would appear that a greater utilization of the fertilizer would have been accomplished had the fertilizer been placed deeper in the soil and more thoroughly mixed with the soil. Further studies of this kind should be made in connection with the placement of fertilizers by fertilizer distributors.

In a few root systems a very interesting root development was found. Often a tap root, although occasionally a secondary root, after penetrating the soil 12 to 18 inches was found to branch profusely and form what appeared to be a supplementary root system for the absorption of water. An example of this is shown in Fig. 4.

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RELATIVE LIME NEEDS OF SULFATE OF AMMONIA AND NITRATE OF SODA AND OF DIFFERENT CROPS[1]

Burt L. Hartwell and S. C. Damon[2]

FERTILIZATION

Prior to this paper, the latest publication of the detailed data from the two-fifteenths acre plats (Nos. 23, 25, 27, and 29) herein involved was Bulletin 160 of the Rhode Island Experiment Station. In that bulletin was summarized the results from 1893 to 1914, especially the comparative effect of lime on different kinds of plants.

In addition to liberal amounts of phosphoric acid and potash, plats 23 and 25 annually have received nitrogen in sulfate of ammonia, and plats 27 and 29 the same amount in nitrate of soda.

The average annual application during the 34 years has been nitrogen, 49 pounds; phosphoric acid, 112 pounds; and potash, 105 pounds; or an equivalent of 1,200 pounds of a 5: 8: 8 fertilizer.

During the war period a total of 1,425 pounds of common salt was used to supplement unusually small applications of potash. Magnesia was added in various sources from time to time to guard against a possible deficiency. Acid phosphate was the source of phosphoric acid, and muriate or sulfate the usual sources of potash. No attention has been given to supplying manganese, although it is now known that in some of the earlier years of the experiment, but only on the nitrate plat which had been limed to neutrality, the chlorosis then observed must have been due to a deficiency of available manganese.

LIMING AND SOIL REACTION

Up to 1915, plats 25 and 29 received an equal amount of lime, but plats 23 and 27 did not receive any lime.

In 1914, the pounds of calcium oxid required to neutralize an acre-foot (3,160,000 pounds of the dry surface soil) by the Veitch method were as follows: Unlimed sulfate plat 23, 7,784; limed sulfate plat 25, 4,607; unlimed nitrate plat 27, 4,210; and limed nitrate plat 29, 3,069.

In 1912, even a low lime-response crop like potatoes was markedly influenced by the greater need of lime with sulfate of ammonia than with nitrate of soda. The bushels per acre were as follows: Plat 23, 128; plat 25, 226; plat 27, 368; and plat 29, 356.

Up to 1915, there had been applied alike to plats 25 and 29 an equivalent of 6,350 pounds of calcium oxid per acre, or an average of

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[1] Contribution No. 352 of the Rhode Island Agricultural Experiment Station, Kingston, R. I. Received for publication June 13, 1927.

[2] Director and Agronomist, and Assistant in Field Experiments, respectively.

289 pounds per year. Only since then some lime has been added also to plat 23 because only high-resistance plants could grow there, and the applications made to plat 25 were larger than to plat 29 with the purpose to bring eventually these two limed sulfate and nitrate plats to the same reaction in order to determine how much more lime is needed with sulfate of ammonia than with nitrate of soda.

Equal reaction has now been attained and it is of interest to observe in Table 1 not only the lime applications but their influence on the pH (pH 7 is neutral; the smaller the number less than this, the greater the acidity) and calcium-oxid absorption of the soil.

TABLE 1.—*Pounds of calcium oxid (CaO) in lime applied per acre*[a] *and its effect on the pH and calcium-oxid absorption.*

	Sulfate of ammonia		Nitrate of soda	
	Less lime Plat 23	More lime Plat 25	No lime Plat 27	Lime Plat 29
1893–1914, CaO in lime applied	0	6,350	0	6,350
1915, CaO in lime applied	500	1,500	0	1,000
1917, CaO in lime applied	500	1,000	0	500
1919, CaO in lime applied	0	1,000	0	500
1920, CaO in lime applied	500	1,000	0	0
1921, CaO in lime applied	500	1,000	0	0
pH	4.6	6.0	5.2	6.4
CaO absorption in p.p.m., Jones method[b]	2,115	——	1,755	——
1922, pH	——	5.9	——	6.0
1924, CaO in lime applied	500	1,000	0	500
pH	4.7	5.6	4.7	5.6
CaO absorption in p.p.m., Jones method	1,890	900	1,544	869
1925, pH	4.5	5.5	4.8	5.6
CaO absorption in p.p.m., Jones method	2,290	1,085	1,643	984
1926, CaO in lime applied	1,500	1,500	0	500
1927, April, pH	5.2	6.3	5.2	6.3
CaO absorption in p.p.m., Jones method	1,564	945	1,620	923
Total CaO in lime applied	4,000	14,350	0	9,350
Average 34 years, CaO in lime applied	118	422	0	275

[a] Prior to 1919, the source of calcium oxid was hydrated lime, since then it has been limestone.

[b] Unless otherwise stated, chemical determinations reported in this paper were made on soil sampled to a depth of about 7 inches or to the change in color.

In Table 1 it may be seen that, including the application of 1921, the 3,500 pounds of calcium oxid applied beginning in 1915 to plat 25 in excess of that applied to plat 29 brought these two plats to about the same pH in 1922. Since that date 1,500 pounds extra of calcium oxid were added and the two plats brought to the same reaction according to the recorded determinations made early in 1927.

ADDITIONAL LIME NEEDS OF SULFATE OF AMMONIA

The average pounds of calcium oxid per year, during the 34 years 1893 to 1926, were 275 applied to the limed nitrate plat and 422 to the greater-limed sulfate plat, or 147 pounds per year more required to attain the given reaction, with the sulfate of ammonia than with the nitrate of soda.

The average annual application of nitrogen during the 34 years was 49 pounds, therefore each pound of nitrogen in sulfate required 3 pounds more of calcium oxid to attain an equal soil reaction; that is, 100 pounds of sulfate of ammonia required about 80 pounds of hydrated lime, or 120 pounds of limestone more than was required by 128 pounds of nitrate of soda supplying the same amount of nitrogen.

Probably more calcium oxid would have been required had the extra lime been so distributed as to have maintained the same reaction on the limed plats during also the first 22 years, for throughout that period the limed sulfate plat was more acid and therefore probably more retentive of alkaline material than the limed nitrate plat. It remains to be ascertained whether the extra calcium oxid required subsequent to 1922, when the two plats had about the same pH, will be more than three times the amount of nitrogen used. From 1922 to 1926, 1,500 pounds of calcium oxid and 285 pounds of nitrogen were used, a relation of 5 to 1.

The complete oxidation of the nitrogen of sulfate of ammonia to nitric acid would result in the two acids, nitric and sulfuric, which would require for neutralization 4 pounds of calcium oxid per each pound of nitrogen. It is probable that the basis of future liming will be 4 pounds more of calcium oxid with the sulfate than with the nitrate, per pound of applied nitrogen. The amount of extra lime required for sulfate of ammonia is so dependent on the size of the applications of the latter that there are recorded here the pounds of nitrogen applied during each period between the lime applications stated in Table 1, namely, 1915, 80; 1916-1917, 100; 1918-1919, 100; 1920, 80; 1921, 40; 1922-1924, 145; and 1925-1926, 140; an average of 57 pounds annually during the 12 years.

The total of the two sources of the same amount of nitrogen used during the 34 years of the experiment was 8,124 pounds of sulfate of ammonia and 10,409 pounds of nitrate of soda, 28% more of the latter having been required to supply the same amount of nitrogen.

In the present experiment only fertilizer chemicals have been used as sources of plant food, the amounts depending on the kind of crops grown.

CROP RESPONSES

It may be seen by the crop records in Table 2 that miscellaneous crops were grown in certain years. They were planted crosswise the plats (30 x 193.6 feet) in 1915, 1919, and 1924; and lengthwise in 1916, 1920, and 1925. In each of the other years (enclosed in parentheses) a uniform crop was grown to promote homogeneity and to introduce organic matter. The reader should realize that in certain years only small areas were available to each crop and not consider the yields as strictly quantitative.

In case of a few crops, the degree of benefit from liming has been modified from that given in Bulletin 160, where low was stated as 0 and 1, medium as 2, and high as 3.

The cotton response was given as low on the basis of 1904 results, but this should apparently be changed to high, although it should be recognized that Rhode Island climate is unsuitable for this crop.

Eggplant is now said to have low response, whereas on the somewhat uncertain results of 1894 the response was given as medium. Peppers apparently exhibit only a medium response, although in 1894 the response was high.

Tobacco, on the basis of results of 1894, was highly responsive, but 1920 results showed low relative response.

Spring wheat seems on the whole to give medium response, although earlier it was said to show low response.

Because muskmelon had repeatedly shown medium lime response in earlier years, no change was made on the basis of the low response of the single year 1915, a year when an unusual amount of phosphoric acid (200 pounds) was used as well as lime, two antidotes of toxic alumina.

The response of mixed hay depends of course upon the species in the mixture which comprise those with low to those with high response in about the following order: Redtop, alsike clover, red clover, timothy, and alfalfa. When spring vetch was sown with oats in 1917, there was less of it on the two more-acid plats. In 1926, the aftermath consisted of 90% alfalfa and 10% red clover on the more-limed plats, 75% alfalfa and 25% red clover on the less-limed sulfate plat, and 55% alfalfa and 45% red clover on the unlimed nitrate plat.

Beets especially were planted frequently so that other crops might be compared with them. They are sensitive to changes in

TABLE 2.—*Relative lime needs of crops and their yield, or average yield, per acre with sulfate of ammonia and with nitrate of soda.*

Degree of benefit from liming	Crop	Year of twentieth century	Sulfate of ammonia		Nitrate of soda	
			Less lime Plat 23 Tons	More lime Plat 25 Tons	No lime Plat 27 Tons	Lime Plat 29 Tons
High	Beets	15, 16, 19, 20, 25	2.12	15.12	9.05	17.71
Low	Buckwheat, green	19, 20	13.47	14.71	12.96	16.91
Low	Carrots	15, 16	3.53	7.68	6.70	3.80
Medium	Cauliflower	24, 25	1.93	4.05	4.24	4.36
High	Celery	24, 25	0.50	18.05	6.36	16.05
High	Cotton, plants	19, 20	0.11	0.82	0.29	0.62
Low	Eggplant, fruit	24	6.80	6.11	8.84	6.44
Low	Gladiolus, bulbs	25	1.64	1.46	1.44	1.46
	Hay, mixed	(17, 18, 22, 23, 26)	2.74	3.61	2.41	3.17
High	Lettuce	25	0.00	12.12	0.48	15.68
Medium	Muskmelon	15	6.48	5.13	5.60	0 .95
High	Parsnips	19, 20	2.93	11.80	10.13	12.43
Medium	Peppers	19, 20	2.42	2.78	2.17	2.35
Low	Pumpkins	15, 16	9.50	10.08	8.38	8.64
Medium	Rape, green	15, 16	18.96	33.66	34.96	35.86
High	Spinach	19, 20, 24, 25	0.15	7.09	1.25	11.14
Medium	Sudan grass, green	15, 16	2.32	7.69	9.14	9.44
Low	Sunflower, green	24	4.80	4.20	6.75	5.40
Low	Tobacco, green	20	20.53	20.48	24.04	18.28
Low	Tomatoes	24	11.68	13.16	16.98	13.76
Low	Watermelons	15	24.98	16.89	20.63	9.47
Medium	Wheat, spring, green	(21)	0.26	6.94	3.15	3.38

acid-soil conditions. In 1915 and 1916, before the reaction of the sulfate plat 25 had been made equal to that of the limed nitrate plat, the crop on plat 25 was less than half of that on the other. In 1919 and 1920 it was nine-tenths and in 1924 fully the equal of that on the limed nitrate plat. This information, together with that in Table 1, will enable the reader to gain an idea of the comparative reaction, at different dates, of the two plats, 25 and 29, which will now be compared especially from the viewpoint of the effect on plant growth of the two sources of nitrogen when used quite liberally at the same soil reaction.

Considering first the other high lime-response crops of which beets were taken as an example, it may be seen that celery, cotton, and parsnips, none of which were grown earlier than 1919 in the present period, yielded practically the same on the two sources of nitrogen. Two very sensitive and short-lived crops, spinach and lettuce, which were usually grown in early spring, produced less with sulfate of ammonia than with nitrate of soda even as late as 1925. The spring crops of spinach and lettuce in 1925 were about three-fourths as great with 60 pounds of nitrogen added April 2 in sulfate of ammonia as in nitrate of soda. They were harvested early in July. By that time the soil nitrates in fallow areas were as high in the sulfate as in the nitrate plat.[3] Nitrate-nitrogen in parts per million of dry surface soil was as follows:

	April				May		June	July
	6	14	17	27	4	21	8	13
Plat 25, sulfate of ammonia	8	19	17	21	26	46	36	48
Plat 29, nitrate of soda	30	38	26	24	30	70	40	38

In view of the extreme sensitiveness of these two crops to alumina, the following determinations of this ingredient in parts per million of dry surface soil may be of significance:

	Plat 23	Plat 25	Plat 27	Plat 29
Oct. 1924, Al_2O_3 soluble in 0.04 N acetic acid.	37	17	21	8
Oct. 1925, Al_2O_3 soluble in 0.10 N acetic acid.	—	95	—	40
Apr. 1927, Al_2O_3 soluble in 0.10 N acetic acid.	—	33	—	17

In general, during the period now under consideration, the crops with medium and low lime-response yielded about as much, or more, with the sulfate as with the nitrate and when the reaction was similar even most of the high lime-response crops yielded about alike with the two nitrogen sources.

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[3] SMITH, JOHN B. The nitrate content of Rhode Island experimental plats as influenced by fertilizers and crops. Jour. Amer. Soc. Agron., 18:888–896. 1926.

SUMMARY

This paper contains the results for 1915 to 1926 of a field comparison, conducted since 1893, of equal amounts of nitrogen in sulfate of ammonia and nitrate of soda accompanied by liberal amounts of phosphorus and potassium.

Prior to 1915, each source of nitrogen had been accompanied by an equal amount of lime, and also had been used without lime. Subsequently, extra lime was applied to the more-limed sulfate plat to make its reaction like that of the limed nitrate plat.

The average pounds of calcium oxid per year during the 34 years was 275 applied to the limed nitrate plat and 422 to the more-limed sulfate plat.

The average annual application of nitrogen was 49 pounds, therefore, each pound of nitrogen required 3 pounds more of calcium oxid to attain an equal soil reaction; that is, 100 pounds of sulfate of ammonia required about 80 pounds of hydrated lime, or 120 pounds of limestone, more than was required by 128 pounds of nitrate of soda supplying the same amount of nitrogen.

When completely oxidized, sulfate of ammonia supplying 1 pound of nitrogen would require for neutralization 4 pounds of calcium oxid. It is believed that this should be the basis of future liming to maintain the sulfate plat at the same reaction as the nitrate plat.

The relative lime-response of the 22 different kinds of crops is expressed as low, medium, or high. Because the two extremely sensitive crops to acid-soil conditions, spinach and lettuce, tended to yield less with sulfate than with nitrate, determinations are included of the soil content of active alumina and of nitrate-nitrogen under the two conditions.

In general, the crop yields were about alike with the two sources of nitrogen when the same reaction of the Merrimac silt loam was maintained.

EFFECT OF A SEMI-LETHAL FACTOR UPON YIELD IN SOYBEANS WHEN PRESENT IN THE HETEROZYGOUS CONDITION[1]

John B. Wentz and Ralph T. Stewart[2]

Extensive self-pollination of corn in the newer breeding projects has brought to light a large number of lethal and so-called semi-lethal defects. These defects are almost invariably recessive in nature and range from those which are completely lethal to others which have only a slight effect upon vigor and yield. It is very apparent that if the homozygous recessive abnormalities occurred in large numbers in a commercial field of corn the yield would be reduced. This source of yield reduction, however, is overcome to a large extent by the fact that, as has been shown by several investigators, only a very small amount of self-pollination takes place in corn. Thus, comparatively few of these defects show up under field conditions. The question arises then, as to the effect of these recessives upon yield when they occur in the heterozygous condition, since it is known that the average commercial variety contains large numbers of defects in the heterozygous state. The authors have some data on the effect of a semi-lethal factor in soybeans upon the yield of individual plants when the factor occurs in the heterozygous condition. While these data are not presented as having a direct bearing on the corn breeding work, it is thought that they may contribute something to the general knowledge of the subject.

RELATED LITERATURE

In an experiment to determine the extent to which recessive abnormalities occur in commercial varieties of corn, Hutchison (2)[3] self-pollinated 2,110 ears of corn representing 468 lots of seed of commercial varieties collected from a number of seed companies and northern experiment stations. Of the 2,110 ears self-pollinated, 67 showed defective seeds. During the following winter, seedling tests were made in the greenhouse. Of 1,872 ears tested, 681, or 36.4%, showed seedling variations. In his discussion of the bearing of the variations upon yield, Hutchison concludes, "The important consideration would seem to be whether plants heterozygous for

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[1] Contribution from the Department of Farm Crops, Iowa State College, Ames, Iowa. Received for publication June 16, 1927.

[2] Associate Professor, Iowa State College, and formerly graduate assistant, Iowa State College, now Associate Professor, A. and M. College, College Station, Texas, respectively.

[3] Reference by number is to "Literature Cited," p. 853.

these abnormalities are less vigorous than the homozygous normals."

Jenkins (3) reported on chlorophyll defects found in seedlings grown from seed of 3,750 self-pollinated ears from 16 varieties and strains of corn and in mature plants grown from seed of 2,500 ears. Fifteen of the 16 varieties or strains segregated for chlorophyll defects. The percentages of segregating progenies ranged from 8.1 to 46.7, with an average of 24.2.

That the corn breeders have quite generally considered the possibility of these abnormal types affecting yield seems evident from the statement by Lindstrom (5) that, "If one could eliminate most of the inferior characters without disturbing the favorable complex, the problem would be solved." Lindstrom shows that the lethal factors are widely distributed on the different chromosomes and that, due to linkages, it would be very difficult to eliminate these undesirable factors without, at the same time, discarding closely linked yield factors.

Jones and Manglesdorf (4), in referring to recessive abnormalities in corn, make the statement, "To what extent, if any, they reduce growth in the heterozygous condition has not yet been established." To secure some data on this question they obtained yields from 25 progenies which still carried the recessives, as compared with 25 progenies from the same lines but from which the abnormalities had been eliminated. The yields were 50.8 and 50.4 bushels, respectively. They made another comparison by finding the average percentage reduction in yield of segregating lines from the first to the fifth generation, by which time the abnormalites were eliminated. This reduction was found to be 57.1% as compared with a reduction of 58.1% for all lines which were free from abnormalities at the start. They concluded from this latter comparison that the elimination of the defectives did not cause any reduction in yield by discarding linked yield factors.

Eldredge (1) has some data which indicate that iojap-striping has no effect upon yield when present in the heterozygous condition. He planted seed from ears known to be segregating for this defect and tested all the normal green plants for the presence of the stripe factor by crossing each one, as pollen parent, onto a pure striped plant. The pure green plants showed no advantage in yield or vigor over those which were heterozygous for the stripe factor.

MATERIAL AND METHODS

The character considered in this paper is a recessive glabrous type in soybeans reported by Stewart and Wentz (6). Originally, it came from a cross of the varieties Soysota and Ogemaw. In the homozygous condition it has a very decided effect upon vigor and yield, each glabrous plant producing only a few small pods.

The F_3 plants from seed of 17 heterozygous F_2 plants were harvested by hand and yields obtained from each individual plant. Seed from each of the plants was then planted in the greenhouse to determine whether it was homozygous normal or heterozygous for the glabrous factor. After it was found which of the F_3 plants were homozygous normal and which ones were heterozygous for the glabrous factor, the mean yield was calculated for each group.

RESULTS

Table 1 shows the mean yields for the homozygous and heterozygous plants, respectively, in each of the 17 progenies and the differences between these means. It will be noted that in nine of the progenies the yield was in favor of the homozygous normal plants, while in the remaining eight progenies the yield was in favor of the plants heterozygous for the glabrous factor. There is a mean difference of 3.83 grams in favor of the homozygous plants. Considering the differences between means and using Student's table for estimating probabilities, P is found to be 0.8668, giving odds of

TABLE 1.—*Showing the effect on yield of soybeans of the recessive glabrous factor when present in the heterozygous condition in normal F_3 plants.*

F_2 plant No.	Number of F_3 plants Homozygous	Number of F_3 plants Heterozygous	Mean yields in grams Homozygous	Mean yields in grams Heterozygous	Differences between means
3	2	5	20.40	14.46	5.94
4	8	14	33.94	32.65	1.29
11	15	17	33.40	24.30	9.10
13	5	12	52.10	21.83	30.27
17	14	15	27.22	33.58	— 6.36
19[a]	13	10	46.62	39.85	6.77
20	5	7	28.92	35.77	— 6.85
25	20	23	42.24	44.79	— 2.55
28	17	28	38.47	31.96	6.51
30	9	22	27.24	25.95	1.29
43	4	6	19.60	21.80	— 2.20
50	9	14	48.03	54.64	— 6.61
64	6	5	29.53	36.44	— 6.91
65	5	18	38.26	39.16	— 0.90
69	4	14	28.55	46.14	—17.59
80	6	8	67.90	47.23	20.67
81	3	6	63.67	30.42	33.25
Totals and means	145	224	38.01	34.17	3.83

[a] In this family there were originally 14 instead of 13 homozygous plants. The yield of one of these plants was only 0.9 gram. Because of its low yield, it was thought not representative of the sample and was omitted from the data.

only 6.51 to 1 that this difference is not due to chance variations in yield.

The odds are not great enough to say with any degree of certainty that the semi-lethal factor has had any effect upon yield. The fact that 8 out of the 17 differences were in favor of the heterozygous plants would, in itself, indicate that there was not a significant difference in favor of the homozygous plants. The odds, however, of 6.51 to 1 cannot be entirely overlooked. It is possible that extensive experiments with this semi-lethal factor would show a more conclusive difference in favor of the homozygous normal plants.

DISCUSSION

The effect which a lethal or semi-lethal factor has upon vigor or yield may be thought of as depending upon the extent to which the normal allelomorph is dominant over the abnormal recessive condition. It seems that in the case of the glabrous soybean the normal condition is completely dominant. It is easy to imagine, however, that as in the inheritance of many of the Mendelian factors, the normal allelomorph may not necessarily be completely dominant. In this case the heterozygous plants would suffer some handicap on account of the presence of the recessive allelomorph. It may be found then, that some of the lethal factors will have an effect upon the vigor and yield of the heterozygous plants while others will not. If this is the case, it will not be possible to establish a general rule as to the effect of the lethal factors upon yield in crop plants.

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NOTE

THE CONTROL OF THE WILD FORM OF CULTIVATED GARLIC

The plant ordinarily known as wild garlic, *Allium vineale* L., possesses tubular dark-green leaves and is one of the most troublesome weeds in America. It is frequently confused with wild onion, *Allium canadense* L., a species with linear leaves and bulbs that do not form "sets" as do the bulbs of wild garlic. In southern Indiana, however, where both of these common plants are serious weeds, a third species of *Allium* is locally troublesome, particularly in the vicinity of Madison.

The newcomer in the weed ranks of the genus *Allium* has been identified as an escaped form of the garden or cultivated garlic, *A. sativum* L., formerly grown in gardens in the vicinity of Madison. It is a tall species, growing to a height of about 2 feet, and possesses long, flat, lanceolate leaves that bear little resemblance to the foliage ordinarily found in the *Allium* genus. Each leaf is folded along what resembles a mid-rib and varies from 1 or 2 or more inches in width. As it reaches maturity, the basal bulb breaks into bulblets that vary from 6 to 20 or more in number, all neatly arranged around the central stem. The following season each bulblet forms a new plant and the process of growth is repeated. The identification of the species was verified by the New York Botanical Garden.

In all the literature devoted to weeds in the genus *Allium* no reference could be found to *A. sativum* as a noxious plant. Since the species is an exceedingly troublesome weed in a restricted area in southern Indiana, an experiment was started three years ago in order to secure information on methods of eradication, inasmuch as the plant resists ordinary cultivation.

An area of about one-fourth acre, solidly infested with the pest, located in an unused part of the Catholic Cemetary on the outskirts of Madison, Indiana, was selected for the work. On account of the method of bulb formation it was believed that fall and spring plowing should eventually eradicate the pest. A check plat was included in the experiment.

The land was first plowed during mid-November, 1924, in such a manner as to expose as many of the bulbs as possible to frost, while at the same time turning the tops completely under. During May, 1925, the plowing was repeated. A noticeable decrease in the stand of garlic occurred the first year, but it was not until the process had been continued for three years that the garlic was completely eradicated. This is essentially the same method, with some variation, that has proved successful in controlling the more widespread and troublesome *A. vineale*.

The garden cultivation of *A. sativum* was not uncommon a half century ago and it is possible that the plant may be spreading in other parts of the country. For small areas, saturating the tops with waste motor oil applied with a sprayer or sprinkling can during April has been found to be effective, but for larger infested areas it is believed that the fall and spring plowing method is advisable. Since nothing has previously been published regarding *A. sativum* as a weed, these brief notes may be of interest.—ALBERT A. HANSEN, *Associate Botanist, Purdue University Agricultural Experiment Station, Lafayette, Indiana.*

BOOK REVIEW

ROOT DEVELOPMENT OF VEGETABLE CROPS

By J. E. Weaver and William E. Bruner. Publications in the Agricultural and Botanical Sciences, edited by Edmund W. Sinnott. McGraw-Hill Book Co., New York. 351 pp. 94 fig. 1927. $4.00.

This is a companion book to Weaver's "Root Development of Field Crops" previously published in the same series. The sources of material used, the treatment of the different crops discussed, and the general style of presentation are similar to those of the preceding book.

After an introductory chapter outlining the general principles involved in the subject and the condition under which the authors' own experimental studies were carried on, the root systems of the following vegetable crops are discussed in successive chapters, varying in length from 4 to 22 pages depending upon the amount of material available in the case of each crop: Sweet Corn; Onion; Leek; Garlic; Asparagus; Rhubarb; Beet; Swiss Chard; Spinach; Cabbage; Cauliflower; Kohl-rabi; Turnip; Rutabaga; Horseradish; Radish; Strawberry; Pea; Beans; Okra; Carrot; Parsley; Parsnip; Sweet Potato; Tomato; Eggplant; Pepper; Cucumber; Muskmelon; Watermelon; Squash; Pumpkin; Lettuce.

A bibliography of 182 references is appended. The general character of the experimental work reviewed and results and conclusions presented is similar to that of the preceding volume, and the mechanical make-up of the book is of the same excellent quality as that of the entire series. (R. W. T.)

ERRATUM

Due to an error in the author's manuscript, the figure 14 in line 10 of page 698 of the August number of this JOURNAL should be changed to 21.

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A CRITICAL STUDY OF SOME OF THE FACTORS CONCERNED IN MEASURING THE EFFECT OF SELECTION IN THE POTATO[1]

J. R. LIVERMORE[2]

Each year it becomes more apparent that there may be a difference in the yielding ability of different strains of the same variety of potatoes. This cannot be entirely accounted for by variation in disease content or other external factors. Oftentimes two strains, growing side by side, vary quite markedly in yield, yet no disease can be detected in either strain.

It is increasingly important, then, that adequate means for measuring these differences should be devised. Failure, in the past, on the part of some investigators to isolate high-yielding strains might well be due, in part at least, to weaknesses in the methods employed to determine the relative yield of the various strains rather than to a fault in the principle of pure line selection when applied to the potato.

It was the purpose of the investigations reported herein to study some of the more obvious sources of error in interpreting results of selection experiments with the potato.

MATERIALS AND METHODS

Certified seed stock was obtained from Hickox-Rumsey Co., Batavia, N. Y. In 1924 this consisted of a pure line of No. 9, a Smooth Rural type potato; in 1925 a pure line of Green Mountain stock; and in 1926 another pure line of the No. 9, Smooth Rural type.

In 1924 and 1926 a crop of clover was turned under for the potato crop, and in 1925 a timothy sod with a little clover was plowed under.

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[1] Published as paper No. 155, Department of Plant Breeding, Cornell University, Ithaca, N. Y. Also presented as a major thesis to the Faculty of the Graduate School of Cornell University in partial fulfillment of the requirements for the degree of doctor of philosophy. Received for publication July 12, 1927.

[2] Extension Instructor in Plant Breeding.

A fertilizer, consisting of 133 pounds of both sodium nitrate and muriate of potash and 800 pounds of acid phosphate an acre, was broadcast each year prior to planting.

Planting was done by hand, in hills 18 inches apart in the row and 36 inches between the rows. The seed potatoes were cut in half from seed end to stem end, and the halves planted in adjacent hills. The half cut off was designated the right half and planted in the first hill; the half remaining in the left hand was designated the left half and planted in the second hill of a pair. This method of planting was followed consistently throughout the plantings of all three years.

Notes were taken as to number of stems, presence or absence of disease, and vigor of the plants. All hills were dug by hand, and the number of tubers and their weight to the nearest ounce determined for each hill.

The plan of planting followed was the same for both 1924 and 1925. This plan is graphically represented in Fig. 1.

The experiment to determine the relative yield of the hills planted with halves of the same seed tuber will hereafter, for the sake of brevity, be referred to in the text as the "halves of same tuber" experiment. This study required 1000 potatoes. In anticipation of an effect of size of seed and location on this factor, it was decided to divide the planting into four blocks.

The first lot of 500 tubers was used to plant blocks 1 and 3. The second lot of 500 tubers was planted in blocks 2 and 4. The mean weight of the tubers in the first lot was 10 grams less than that of the second lot. Each lot varied among themselves within a range of 10 grams. The smaller-sized lot averaged about 4 ounces in weight, allowing a 2-ounce seed piece for each hill. The larger-sized lot averaged about 4⅓ ounces.

The "halves of same tuber" experiment was planted in rows 50 hills long and each block contained 10 of these rows. There were four blocks in 1924 and in 1925. The single-hill skip and double-hill skip experiments were each planted in 10-row blocks. One block of each of these three studies comprised a series (Fig. 1). There were four of these series in 1924 and in 1925.

A system of numbering the rows was devised to simplify the records. Each row number contains three digits. The first digit indicates in which series the row was located, i. e., 1, 2, 3, or 4 for first, second, third, or fourth series, respectively. The second digit indicates the type of experiment concerned, *viz.*, 1 refers to the "halves of same tuber" study; 2 to the single-hill skip study; and 3 to the double-hill skip study. The third digit refers to the actual number of the row within the given block, 0 for the first row and so on up to 9 for the tenth row. Row 126, then, indicates that it is the seventh row in the single-hill skip experiment and the block is located in the first series. Row 330 indicates that it is the first row in the double

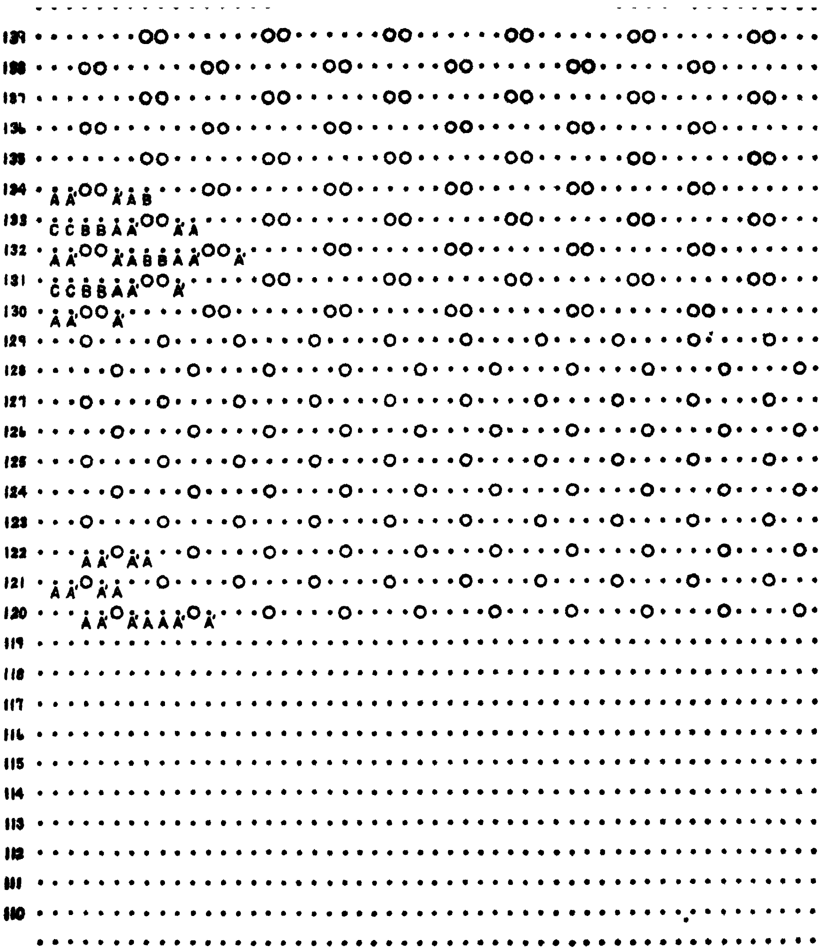

FIG 1.

hill skip study and in the third series. Row 111 indicates it is the second row in the "halves of same tuber" experiment and the block is located in the first series, and so on.

Data from the inside rows of each of these 10-row blocks were used in these studies, rows 111 to 118 inclusive, 211 to 218 inclusive, etc; 121 to 128 inclusive, 221 to 228 inclusive, etc; 131 to 138 inclusive, 231 to 238 inclusive, and so on. All rows ending in 0 or 9 were considered guard rows for their respective blocks, the data from these not being used in the calculations. A guard hill was planted at each end of every 50-hill row.

COMPARISON BETWEEN YIELD OF HILLS PLANTED WITH HALVES OF SAME SEED TUBER

In order to study the effects of missing hills, competition between adjacent plants, and competition between rows, it is necessary that one have two similar hills so arranged that one of the pair shall be influenced by and the other member of the pair shall *not* be influenced by the particular condition one wishes to study. It would seem that in studying the potato the above condition could best be met by cutting a tuber in half and planting a pair of hills from the resulting pieces. Certainly equal pieces of a portion of a vegetatively propagated plant should approach equality in their ability to yield, if not actually being equal. This, then, becomes the first problem, to determine whether under field conditions tubers can be cut so that the resulting halves will yield equally.

The first work of this kind, to the author's knowledge, was that reported by Stewart (6)[3] in 1919. He used a continuous row of hills, in which each pair of adjacent hills was planted from a single tuber, as a check on the effect of missing hills in adjoining rows. In this experiment 85 pairs were found to have a mean difference in yield of 20.7 ±1.1%. Further, it was found that the second member of each pair of hills outyielded the first member by 1.24 ounces on the average.

In 1921 Stewart (7) published further data on this point. In studying 429 pairs of hills he reports a difference of 1.1 ±0.2642 ounces in favor of the first member of each pair. Stewart designates the first member of a pair of hills from the same seed tuber as *c* and the second member as *c'*. Then the *c* hills outyielded their sister hills, the *c'* hills, by 1.1 ounces. This difference is more than four times its probable error and the odds are 190 to 1 that it was not due to chance alone. One would expect the difference to approximate zero.

Stewart stated in his summary, "The probable error, usually considered a reliable test of the statistical significance of mathematical results in which chance is a factor, has proved misleading in one instance in which it has been used in this work." By arbitrarily designating the first member of each pair as *c* and the second member as *c'* Stewart has immediately removed the problem from the realm of chance. If there is any factor at work which would favor one member of the pair at the expense of the other, such a condition would be magnified by using large numbers. In this case 429 pairs would increase a slight difference quite materially, enough so that it might be statistically significant.

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[3] Reference by number is to "Literature Cited," p. 895.

In passing it might be stated that the probable error, or any other measure of the significance of a difference between two means, will not indicate to what the difference is due; its sole purpose is to show whether the difference is a significant one or not. So in this case the difference is significant but no indication of its cause can be derived from the probable error.

In a preliminary experiment the writer found in cutting 153 potatoes in half that the mean difference in weight of the two halves was 3.4 ±0.27 grams and the standard deviation was 4.9 ±0.19 grams. This difference was in favor of the left half. Using Sheppard's probability tables, the odds were found to be greater than 10,000 to 1 that the left half of the tuber was larger than the right. The probable explanation of this is that in cutting the tuber the operator unconsciously allows the knife to veer to the right for fear of cutting the left hand.

It is then reasonable to suppose that this condition would hold with any experiment having to do with the cutting in half of potatoes. In Stewart's experiment then, it might well be that the *c* plants, which outyielded their mates, were derived from the left half of the tuber. Even the small advantage of a few grams heavier seed piece might conceivably occur consistently enough so that a significant difference in yield could be demonstrated in a population of paired hills. If Stewart had labeled the hills *c*, *c'*, *c'*, *c*, *c*, *c'*, etc., instead of *c*, *c'*, *c*, *c'*, *c*, etc., it is probable that the difference in yield of the sister hills from a single tuber would have approximated zero. In this manner he would have averaged this advantage instead of multiplying it.

As further proof that the difference Stewart found might well be accounted for by a slightly yet consistently larger seed piece in one member of each pair of hills, the following data are presented. In 1924 the seed pieces planted in blocks 1 and 3 weighed 56.7 ±2.2 grams, in blocks 2 and 4 the seed pieces weighed 61.7 ±2.2 grams. The mean yield for blocks 1 and 3 was 33.4 ±0.21 ounces and for blocks 2 and 4, 35.8 ±0.20 ounces. The difference, 2.4 ±0.29 ounces, is significant as the D over P. E. value is 8.3 and the odds are greater than 10,000 to 1. A similar result was obtained in 1925. The mean yields were 26.1 ±0.22 and 29.0 ±0.23 ounces, respectively. The difference, 2.9 ±0.32 ounces, is significant as its D over P.E. value is 9.1 and the odds are greater than 10,000 to 1.

Although these data are mathematically significant, it would be rash indeed to ascribe all the increase in yield to the influence of size of seed piece. It might well be that much of this increase is due to the difference in soil conditions. Be that as it may, the fact remains, as borne out by many investigators, that increase in size of seed piece will increase total yield. So small an increase in size of seed piece as one-eighth of an ounce may increase the yield an appreciable amount.

It was pointed out above that the two pieces of a tuber supposedly cut in half may vary in weight as much as 4 or 5 grams. The data and discussion indicate that the effect on yield of a slight difference in size of seed piece may be measured. It is quite probable, then, that the difference Stewart found, which was 1.1 ±0.2642 ounces, was due to the difference in size of seed piece.

If this statement is accepted, why did not the writer find a difference in yield between the halves of the same seed tuber? The only explanation he has to offer is that knowing that the left half would be the larger, he made a consistent effort to cut beyond what seemed to be the center and so overcame the effect of the fear of cutting the left hand. This is evidenced by the data, which show that though the preponderance of the differences are in favor of the left half, there are a few blocks in which the odds are in favor of the right half. In these latter instances too much latitude was allowed for the effect of the fear of cutting the left hand.

The marked effect on yield of so small a factor as a difference of one-sixth of an ounce in the size of seed piece further emphasizes the need for greater caution in all factors concerned in potato experiments. Too many of the field trials with potatoes that have been reported have entirely neglected or overlooked the necessity of similar treatment in all respects for the different strains. It is quite probable that the conclusions in some of these papers would be completely reversed if some of these less obvious factors had been studied more closely and their effect considered when interpreting the results of an experiment.

INVESTIGATION AND DISCUSSION

The data from the "halves of same tuber" study offer an ideal field for the use of Student's (9) method of comparing paired experiments. In Table 1 the row numbers are given indicating which block the data represent; *n* equals the number of pairs used; the odds are listed in the next column; and the letter (L or R) indicates whether the left half or the right half produced the greater yield. The average weight of seed tuber used is also indicated.

The odds were first determined for each row, then for each block (eight rows only) separately, for each two blocks planted from same weight seed tubers, and finally for all four blocks treated as one experiment. These results for 1924 (Smooth Rural) and 1925 (Green Mountain) are tabulated in Table 1.

Of the 14 comparisons indicated in Table 1 there are only two where the odds are great enough to indicate a significant difference in yield between sister hills. It is of interest to note that both of these are in favor of the left half of the seed tuber. The highest odds that the right half outyields the left half occurred in the 411 to 418 block in 1924, where the odds were 10:1(R).

TABLE 1.—*Comparison by Student's method of the yield from hills planted with right and left halves of same seed tuber.*

1924				1925			
Block No.	Average weight seed tuber in grams	n	Odds	Block No.	Average weight seed tuber in grams	n	Odds
1	113.5	198	13:1 (L)	1	113.0	170	2:1 (R)
3		200	<2:1 (L)	3		191	8:1 (R)
1 and 3		398	7:1 (L)	1 and 3		361	9:1 (R)
2	123.5	200	221:1 (L)	2	124.0	188	1:1 (L)
4		200	10:1 (R)	4		169	49:1 (L)
2 and 4		400	1:1 (L)	2 and 4		357	15:1 (L)
All 4 blocks	118.0	798	7.1 (L)	All 4 blocks	118.5	718	<2:1 (L)

In 1925, considering the two blocks planted from the smaller potatoes, the odds would seem to indicate that the right half outyielded the left half. The reverse is true in the blocks planted with the larger seed tubers. Here the odds would indicate that the left half outyielded the right half and in one instance the odds are great enough to indicate significance, 49:1(L).

Why a difference like this should be obtained in the case of the Green Mountains in 1925 and not in the Smooth Rurals in 1924 is a question, the solution of which must await more data from similar experiments. Of course the odds are small and it might well be due to chance alone.

When all the data for each year are treated as one experiment, the odds are so low as to indicate no significant difference. In 1924, the odds were 7:1(L), and in 1925 the odds were <1:1(L). One might conclude, then, that in so far as these experiments are concerned, there is no significant difference in yield between hills planted with halves of the same seed tuber. Though the odds are low it is worthy of note that they are in favor of the left half for both years.

A second method of analyzing these data was to determine the mean yields in ounces of the right and left halves and then find the difference with its probable error. If a difference is more than three times its probable error, it is considered significant. In Table 2 these determinations have been set forth.

In the first part of the table the data for 1924 indicate that there is no significant difference in the yield from the halves of the same tuber. Whether the differences are computed for a single eight-row block or an average of the two blocks planted from the same sized tuber, the yields are not significantly different. The greatest difference is that for the block 211 to 218, 1.5 ±0.56, which is only 2.7 times its probable error. Taking all rows together, the mean yield in ounces for the right half is 34.3 ±0.21 and that for the left half 34.9 ±0.21. Their difference is 0.6 ±0.30 ounce with a D over P. E. value of only 2.0. This difference is not considered significant. It may be stated, then, that for the conditions of this experiment there is no significant difference in yield between hills planted with halves of the same seed tuber.

The 1925 data show a similar result. The greatest difference was less than twice its probable error. The mean yields of the two halves in block 211 to 218 were exactly the same. Their difference was

TABLE 2.—*Comparison of the yield, in ounces, of hills planted with halves of the same seed tuber.*

Block No.	Standard deviation	Mean yield of right half	Difference	Mean yield of left half	Standard deviation
			1924		
1	9.5±0.32	35.4±0.46	1.2±0.66	36.6±0.48	10.0±0.34
3	7.1±0.24	30.7±0.34	0.2±0.49	30.9±0.35	7.4±0.25
1 and 3	8.9±0.21	33.0±0.30	0.7±0.44	33.7±0.32	9.4±0.22
2	8.0±0.27	36.1±0.38	1.5±0.56	37.6±0.41	8.7±0.29
4	9.5±0.32	35.0±0.45	0.5±0.56	34.5±0.34	7.1±0.24
2 and 4	8.7±0.21	35.6±0.29	0.5±0.39	36.1±0.26	7.8±0.19
All 4 blocks	8.9±0.15	34.3±0.21	0.6±0.30	34.9±0.21	8.7±0.15
			1925		
1	8.0±0.29	24.5±0.41	0.6±0.55	23.9±0.37	7.2±0.26
3	9.1±0.31	28.3±0.44	1.0±0.62	27.3±0.44	9.1±0.31
1 and 3	8.8±0.22	26.5±0.31	0.8±0.43	25.7±0.30	8.4±0.21
2	10.1±0.35	27.8±0.50	0.0±0.69	27.8±0.47	9.6±0.33
4	9.0±0.33	29.6±0.47	1.4±0.65	31.0±0.45	8.6±0.32
2 and 4	9.8±0.25	28.6±0.35	0.7±0.49	29.3±0.34	9.5±0.24
All 4 blocks	9.2±0.16	27.6±0.23	0.1±0.33	27.5±0.23	9.0±0.16
			1926		
1	10.4±0.40	31.9±0.56	0.1±0.79	31.8±0.56	10.4±0.40

0.0 ±0.69. The difference between the mean yields for all four blocks was 0.1 ±0.33. Mathematically speaking, then, there is no difference between the yields of halves of the same tuber in the Green Mountain type as well as in the Smooth Rural type.

In 1926 a pure line of the Smooth Rural type was used. The average weight of the seed tubers planted was 145 ±4.5 grams, or 5.1 ±0.17 ounce. The mean yield of the right half was 31.9 ±0.56 ounces and that of the left half 31.8 ±0.56 ounces. The difference was 0.1 ±0.79 ounce. This difference, obviously, is not significant.

It is evident from the three years' data given above that when chance is allowed free rein there is no significant difference in the yield from one half of a tuber compared with the yield from the other half. Using two different types of potatoes, the Smooth Rural and the Green Mountain, and using data from three seasons, no significant difference was found.

Since it is safe to assume that with comparatively large numbers there will be no difference in yield between halves of the same seed tuber, we may proceed to our next problem, that of the effect of missing hills.

EFFECT OF MISSING HILLS

Fitch and Bennett (1), in 1910, reported that the hills on either side of a single skip made up 50% of the loss. They used small numbers and made little attempt to provide uniform conditions for the adjacent hills that were used to measure the effect of the missing hills.

Stewart (6), in 1919, reported some work on the effect of missing hills. He cut the seed tubers in half lengthwise, the halves being planted in adjacent hills. Two tubers were planted in this way, giving four hills, the next hill was skipped, and then four more hills planted. By this method, assuming halves of tubers to yield equally, it was possible to attribute the increase in yield of the hill adjacent to the skip over the yield of the inside member of the pair of hills to the influence of the skipped hill. The percentage increase of the one over the other would indicate to what extent adjacent hills might make up the loss. He obtained data from 351 pairs of hills and found that the adjacent hills together made up 46.4% of the loss in total yield.

In 1921, Stewart (7) reported another experiment with 145 pairs. It was found that the adjacent hills made up 53.8% of the loss in total yield due to a single skip. He also studied the effect of a triple-hill skip and found that the yield of the adjacent hills was increased less by the triple- than by the single-hill skip. The difference, however, was less than its probable error, so was not considered significant. In his "missing hill" studies Stewart used the Rural type of potatoes only.

Stewart (6, page 63) states, "From even a casual examination of the data it is evident that the exterior plants outyielded the interior ones; but the exact amount of the difference depends upon the method of calculating it,..........." He goes on further to say that the simplest way to measure the increase would be to find the difference between the average yield of all the interior plants and the average yield of all the exterior plants and divide the difference by the average yield of the interior plants. He says that this percentage would be only approximately correct as no exterior plant is strictly comparable with any other interior plant than its own mate. Because of this, he states that the correct way would be to determine the percentage increase in yield of each exterior plant compared with its own interior plant. The average of these percentages would be an accurate measure of the effect of missing hills. Be that as it may, it would seem that the determination of the difference in ounces between the yield of each exterior plant and its own interior mate would satisfy the above condition fully as well. This method of comparison has the further advantage of not using percentages except as a final expression of the relation of the mean difference to the mean yield of the interior plants.

It has been pointed out by some biometricians that percentage is a dangerous yardstick to use as a measure. Oftentimes the results are misleading when computations are on a percentage basis and conclusions drawn that cannot be justified by other analyses of the data. Student (10) has this to say concerning the use of percentages, "This is not to say that percentages should never be used; that is another method of substituting one figure for two which has its uses, but percentages should be used with the greatest care, they are fertile mothers of fallacy." With these conflicting viewpoints in mind, it seems desirable to utilize the data from the missing hill study as material to test the truth of these two statements, since these data lend themselves very well to a study of this kind.

The comparison and discussion of the two methods of measuring the effect of missing hills will necessitate the use and repetition many times of a statement as to what is meant by these two methods. A detailed description of each method will be given and a short term applied to each to facilitate the discussion. The first method involves a computation of the percentage difference in yield of each exterior hill (A′) adjacent to the skip compared with its interior mate (A) of the pair A′A in the single-hill skip. These percentage differences are summed and their mean determined. This mean represents the increase or decrease in yield of the exterior hills compared with the interior hills due to the effect of the missing hill. In the double-hill skip study there will be two comparisons made in a similar manner. The difference in yield of each exterior hill (A′) of the outside pair of hills (A′A or AA′) contrasted with its nearest unrelated hill (B) of the inside pair of hills (BB) is expressed in percentage of the yield of B. Similarly, the interior hill (A) of the outside pair of hills (A′A or AA′) is contrasted with its adjacent unrelated hill (B) of the inside pair of hills (BB). This difference is expressed in percentage of the yield of B. The individual percentage differences are summed and their means computed. The mean percentage difference of A′ compared with B plus the mean percentage difference of A compared with B should represent the effect of a double-hill skip. The determination of the difference between each pair of hills in percentage will be referred to hereafter in the text as the "percentage difference" method.

The second method involves the determination of the mean difference in yield in ounces between each exterior hill (A′) and its interior mate (A) of the pair of hills A′A or AA′ in the single-hill skip study. In the double-hill skip experiment the mean difference in yield in ounces between each exterior hill (A′) of the outside pair of hills (A′A or AA′) and its nearest unrelated hill (B) of the inside pair of hills (BB) is determined. The mean difference in ounces between the yield of the interior hill (A) of the outside pair (A′A or AA′) and its adjacent unrelated hill (B) of the inside pair of hills (BB) is also found. The mean yields in ounces of the A hills of the single skip and the B hills of the double skip are determined. The mean difference in ounces between A′ and A is divided by the mean yield in ounces of A. This quotient, expressed in percentage, should represent the effect of a missing hill in so far as the increase in yield of A′ is a measure of it. The mean difference in ounces between A′ and B and the mean difference in ounces between A and B are divided by the mean yield in ounces of B. The summation of these two values should represent the effect of two missing hills on the yield of the adjacent hills in so far as the increase in yield of A′ over B and of A over B is a measure. In the discussion this method will be referred to as the "actual difference" method. These comparisons of A′ with A, A′ with B, and A with B will be more easily understood if the reader will refer to Fig. 1.

INVESTIGATION AND DISCUSSION

EFFECT OF A SINGLE SKIP

The 800 tubers required in this experiment were divided by weight into two lots. One lot of 400 weighed 133.0 ±4.0 grams, or about 4.7 ounces, and the other lot of 400 weighed 142.5 ±4.5 grams, or about 5.0 ounces. Each tuber was cut in half and planted in two adjacent hills. A hill was left vacant after each four planted hills. There were 40 planted hills and 10 skips in each row. Ten of these rows made up a block and four blocks were planted in 1924 and 1925. By referring to Fig. 1 one may obtain a clearer picture of the arrangement. Only 10 rows were planted in 1926.

The hill adjacent to the skip was designated the exterior hill (A′) of the outside pair of hills (A′A) and its sister hill as the interior hill (A) of the pair (A′A). Blocks 1 and 3 (rows 120 to 129 and 320 to 329) were planted with the smaller tubers. Blocks 2 and 4 (rows 220 to 229 and 420 to 429) were planted with the larger tubers. The data for the three years are presented in Tables 3, 4, and 5.

Comparison by percentage differences.—The mean percentage increase in the yield of the exterior hill (A′) over its interior mate (A) as given in Table 3 is 27.0 ±0.84 for 1924. The mean for 1925 is 25.0 ±1.22% and that for 1926 is 20.0 ±1.60%. The word "range" is used to designate the spread of the single observations from the lowest minus, or percentage decrease, to the highest plus, or percentage increase. The widest range is in 1925 from minus 91.3 to plus 300.0%. The narrowest range is that for 1926 from minus 35.0 to plus 133.3%. The range for 1924 is from minus 52.4 to plus 179.9%. Apparently the effect of a missing hill is quite variable. To determine the effect of a missing hill on the yield of the adjacent hills, one should double the percentage increase values as given in Table 3. Then for 1924 the percentage increase in yield of the adjacent hills would be 54.0 ±1.68; that for 1925, 50.0 ±2.44; and that for 1926, 40.0 ±3.20. From these data one might conclude that a missing hill will increase the yield of the two adjacent hills from 40 to 55%. The Green Mountains in 1925 and the Smooth Rurals of 1924 and 1926 are not significantly different in their response to the stimulus of the missing hill.

Comparison by actual differences.—The data for the comparison by actual differences for the three years concerned in the single-hill skip study are presented in Tables 4 and 5. From Table 4 one finds that the mean difference in ounces between the exterior hill (A′) and its interior mate (A) is 8.1 ±0.24 for 1924. The mean yield of A as given in Table 5 is 35.2 ±0.22. The percentage increase due to the

TABLE 3.—*Percentage increase in yield of exterior hill (A′) over its interior mate (A) of the A′A pair of hills, due to a single-hill skip.*

Block No.	Average weight seed tuber in grams	n	Mean	Standard deviation	Percentage range
			1924		
1	133.0	154	31.1±1.75	32.2±1.24	—25.0 to +179.9
3		156	23.1±1.54	28.6±1.09	—52.4 to +173.9
1 and 3		310	27.1±1.18	30.7±0.83	
2	142.5	152	24.4±1.58	28.8±1.12	—44.0 to +150.0
4		154	29.2±1.79	32.9±1.26	—44.4 to +130.4
2 and 4		306	26.8±1.20	31.0±0.85	
All 4 blocks	137.7	616	27.0±0.84	30.8±0.59	—52.4 to +179.9
			1925		
1	135.0	130	25.9±2.76	46.6±1.95	—53.6 to +300.0
3		138	26.8±2.62	45.7±1.86	—48.5 to +238.4
1 and 3		268	26.4±1.90	46.2±1.35	
2	146.0	133	20.6±2.01	34.4±1.42	—68.0 to +130.4
4		139	26.7±2.24	39.2±1.59	—91.3 to +235.3
2 and 4		272	23.7±1.52	37.1±1.07	
All 4 blocks	140.5	540	25.0±1.22	41.9±0.86	—91.3 to +300.0
			1926		
1	165.0	146	20.0±1.60	28.6±1.13	—35.0 to +133.3

missing hill obtained by dividing the former by the latter mean is 23.0 ±0.01. In 1925 the percentage increase is 17.8 ±0.01, obtained by dividing the mean difference, 5.4 ±0.28 ounces, by the mean yield of A, 30.3 ±0.29 ounces. The percentage increase in yield of A′ over A in 1926 is 14.7 ±0.01, the result of dividing the mean difference between A′ and A of 6.0 ±0.56 ounces by the mean yield of A, namely, 40.8 ±0.84 ounces. The percentage increases in yield of A′ over A for 1924, 1925, and 1926, as determined by the "actual difference" method, are lower than the percentage increases in yield for 1924, 1925, and 1926, respectively, as determined by the "percentage difference" method. According to the latter method, a missing hill increases the yield of the adjacent hills from 40 to 55%, yet a comparison by actual differences, as described above, indicates that a missing hill increases the yield of the adjacent hills from about 30 to 46%. A difference as great as this should cause one to consider carefully which method should be used to measure this effect.

EFFECT OF A DOUBLE SKIP

In the double-hill skip study, large potatoes were used for seed. They ranged from 6 to 7 ounces in weight. The plan of planting is shown in detail in Fig. 1. Three tubers were cut in half and the sister halves were planted in adjacent hills. After three pairs of hills had been planted in this manner two hills were skipped and then

TABLE 4.—*Increase in yield in ounces of exterior hill (A′) over its interior mate (A) of the A′A pair of hills due to a single-hill skip.*

Block No.	Average weight seed tuber in grams	n	Mean	Standard deviation	Range in ounces
1924					
1	133.0	154	9.1±0.48	8.9±0.34	—11 to +32
3		156	6.6±0.45	8.4+0.32	—22 to +40
1 and 3		310	7.8±0.34	8.8±0.24	
2	142.5	152	7.8±0.48	8.8±0.34	—22 to +45
4		154	9.0±0.52	9.6±0.37	—12 to +35
2 and 4		306	8.4±0.35	9.2±0.25	
All 4 blocks	137.7	616	8.1±0.24	9.0±0.17	—22 to +45
1925					
1	135.0	130	4.5±0.50	8.5±0.36	—17 to +29
3		138	5.2±0.56	9.8±0.40	—24 to +32
1 and 3		268	4.9±0.38	9.2±0.27	
2	146.0	133	4.8±0.58	10.0±0.41	—34 to +30
4		139	7.0±0.58	10.2±0.41	—21 to +40
2 and 4		272	5.9±0.42	10.2±0.29	
All 4 blocks	140.5	540	5.4±0.28	9.7±0.20	—34 to +40
1926					
1	165.0	146	6.0±0.56	10.0±0.39	—21 to +31

TABLE 5.—*Percentage increase in yield of exterior hill (A′) over its interior mate (A) as determined by dividing mean difference in ounces between A′ and A by the mean yield in ounces of A. Single-hill skip data.*

Block No.	n	Mean yield of A in ounces	Mean difference A′–A in ounces	Percentage difference
1924				
1	154	34.7±0.49	9.1±0.48	26.2±0.01
3	156	34.5±0.46	6.6±0.45	19.1±0.01
1 and 3	310	34.6±0.34	7.8±0.34	22.5±0.01
2	152	36.1±0.40	7.8±0.48	21.6±0.01
4	154	34.6±0.38	9.0±0.52	26.0±0.02
2 and 4	306	35.8±0.28	8.4±0.35	23.5±0.01
All 4 blocks	616	35.2±0.22	8.1±0.24	23.0±0.01
1925				
1	130	27.4±0.53	4.5±0.50	16.4±0.02
3	138	29.2±0.56	5.2±0.56	17.8±0.02
1 and 3	268	28.3±0.39	4.9±0.38	17.3±0.01
2	133	31.0±0.59	4.8±0.58	15.5±0.02
4	139	33.6±0.56	7.0±0.58	20.8±0.02
2 and 4	272	32.3±0.41	5.9±0.42	18.3±0.01
All 4 blocks	540	30.3±0.29	5.4±0.28	17.8±0.01
1926				
1	146	40.8±0.84	6.0±0.56	14.7±0.01

another set of three pairs of hills followed by another skip of two hills, and so on. There were six such skips in each row.

Comparison by percentage differences.—The data in Table 6 show the mean percentage increase of the exterior hill over the interior hill, as determined by the "percentage difference" method, for the three years, together with the standard deviations and their errors. In spite of the wide range in the figures the data are fairly consistent. In 1924 for the Rurals the mean of 377 comparisons is 34.1 ±1.13%, in 1925 for the Green Mountains it is 29.7 ±1.66%, and in 1926 for another pure line of Rurals the mean is 30.1 ±1.67%.

It seemed to the writer that there should be a greater difference between the effect of a double skip compared to a single skip than is shown by these figures. To find out if by any chance the second hill from the skip benefited from the double skip, another analysis of the data was made.

TABLE 6.—*Percentage increase in yield of exterior hill (A') over its interior mate (A) of the A'A pair of hills due to a double-hill skip.*

Block No.	Average weight seed tuber in grams	n	Mean	Standard deviatoin	Percentage range
			1924		
1	152.0	96	42.2±1.87	27.1±1.32	—18.9 to +125.0
3		93	23.3±2.00	28.6±1.41	—38.8 to +120.0
1 and 3		189	32.9±1.44	29.4±1.02	
2	161.0	94	37.4±2.91	41.8±2.06	—29.8 to +310.5
4	170.5	94	33.0±1.94	27.9±1.37	—17.7 to +115.0
All 4 blocks	158.9	377	34.1±1.13	32.6±0.80	—38.8 to +310.5
			1925		
1	157.0	84	35.8±3.41	46.3±2.41	—50.0 to +300.0
3		76	28.8±4.09	52.8±2.89	—53.8 to +220.0
1 and 3		160	32.5±2.64	49.6±1.87	
2	168.0	85	29.3±2.99	40.9±2.12	—43.2 to +200.0
4	113.0	86	24.8±2.73	37.6±1.93	—31.4 to +140.0
All 4 blocks	148.7	331	29.7±1.66	44.7±1.17	—53.8 to +300.0
			1926		
1	155.0	83	29.1±2.21	29.9±1.57	—26.9 to +100.0
2	177.5	73	31.2±2.53	32.1±1.79	—33.3 to +142.9
Both blocks	166.2	156	30.1±1.67	31.0±1.18	—33.3 to +142.9

Since the seed stock used each year was from a tuber line and any entire block had been planted with approximately equal weight seed tubers, it would seem that adjacent hills from unrelated tubers should yield approximately the same. By referring to Fig. 1 it will be seen how this comparison could be made. The yield of the interior member (A) of the pair of hills adjacent to the double skip, was compared with the yield of the adjacent hill (B), which was a member of the inside pair of hills (BB). This inside pair of hills (BB) was separated from the double skip by a pair of hills (A'A) on either side.

At first thought it seemed that the interior member (A) of the pair of hills (A'A or AA') adjacent to the double skip might be reduced in yield because of the increased vigor of the exterior member (A'), which is adjacent to the skip. With this in mind, if the interior member (A) outyielded the adjacent unrelated hill (B) the sign of the percentage increase was plus; if the interior member (A) yielded less than the adjacent unrelated hill (B), the sign was minus. The data are presented in Table 7. The mean percentage increase for 1924 is 3.0 ±1.02, that for 1925 is 13.1 ±2.28, and that for 1926 is 14.2 ±3.40. It is of interest to note here that the range of these individual percentage differences seems to be correlated with the mean percentage difference, that is, the narrower the range between the minus and plus variates, the lower the mean percentage increase of A over B. This will be discussed more in detail later.

TABLE 7.—*Percentage difference in yield between adjacent hills from halves of unrelated tubers. Hills A and B compared.*

Block No.	Average weight seed tuber in grams	n	Mean	Standard deviation	Percentage range
			1924		
1	152.0	88	1.3±2.21	30.67±1.56	+144.4 to —52.6
3		85	4.5±1.97	26.95±1.39	+ 74.4 to —60.0
1 and 3		173	2.9±1.47	28.71±1.04	
2	161.0	86	6.1±2.24	30.78±1.58	+ 83.3 to —64.1
4	170.5	86	—0.1±1.91	26.24±1.35	+ 76.2 to —51.2
All 4 blocks	158.9	345	3.0±1.02	27.97±0.72	+144.4 to —64.1
			1925		
1	157.0	69	13.1±4.62	56.95±3.27	+200.0 to —68.2
3		61	24.2±6.75	78.17±4.77	+275.0 to —75.5
1 and 3		130	18.3±3.84	64.88±2.71	
2	168.0	58	7.3±4.63	52.24±3.27	+154.5 to —82.0
4	113.0	75	8.4±4.13	53.07±2.92	+200.0 to —72.6
All 4 blocks	148.7	263	13.1±2.28	54.83±1.61	+275.0 to —82.0
			1926		
1	155.0	80	12.5±4.68	62.10±3.31	+250.0 to —74.2
2	177.5	79	15.9±5.16	67.96±3.65	+293.3 to —76.1
Both blocks	166.2	159	14.2±3.40	63.50±2.40	+293.3 to —76.1

The mean percentage increase values in Table 7 indicate that the influence of a double skip may be evidenced by the increased yield of the second hill (A) from the skip. It would seem logical that the true measure of the effect of a double-hill skip would be represented by the sum of the mean percentage increases as set forth in Tables 6 and 7. These sums appear in Table 8.

The data in Table 8 would indicate that a double-hill skip increases the yield of the two adjacent hills about 50%. The sums of the means are about the same. The sum for 1924 is 37.1 ±1.52, that for 1925 is 42.8 ±2.82, and that for 1926 is 44.3 ±3.79. The greatest difference between any two of these is that between 1924 and 1926, the two years that Smooth Rural seed stocks were used. This difference is less than twice its probable error and is not considered significant. These results are for either side of a double skip, hence they should be doubled to determine the total increase in yield of the four adjacent hills due to two missing hills.

As both the exterior hill (A′) and the interior hill (A) are apparently affected by the double skip, it would seem that the logical basis of comparison to determine change in yield of A′ and A would be the adjacent unrelated hill (B) of the inside pair of hills (BB). This pair of hills (BB) would hardly be affected by the skip in the same row, but they may or may not be affected by the missing hills directly opposite in the adjacent rows. In any event it would seem logical that they would be equally affected if affected at all. The hill B, then, should be a standard with which one may compare A′ and A. The B hill is not an absolute standard because it is possible that the yield of the BB hills might be increased by the missing hills opposite them in the adjoining rows. The percentage increases, then, of A′ or A over B are but relative to B and only represent the true increase

TABLE 8.—*The effect of the double-hill skip on the adjacent pair of hills, A′A, as measured by the increase in yield.*

Summation of Percentage Increase in Yield of A′ over A and of A over B

	1924	1925	1926
Percentage increase in yield of the exterior hill A′, of the pair of hills (A′A) adjacent to the skip, over its sister hill A	34.1±1.13	29.7±1.66	30.1±1.67
Percentage increase in yield of the interior hill A, of the adjacent pair A′A, over its unrelated adjacent hill B	3.0±1.02	13.1±2.28	14.2±3.40
Total percentage increase	37.1±1.52	42.8±2.82	44.3±3.79

Summation of Percentage Increase in Yield of A′ over B and of A over B

	1924	1925	1926
Percentage increase in yield of the exterior hill A′, of the pair of hills (A′A) adjacent to the skip, over the neighboring unrelated hill B of the inside pair of hills BB	34.8±1.47	37.6±2.70	39.9±3.71
Percentage increase in yield of the interior hill A, of the adjacent pair A′A, over its unrelated adjacent hill B.	3.0±1.02	13.1±2.28	14.2±3.40
Total percentage increase.	37.8±1.79	50.7±3.53	54.1±5.03

in yield of A′ or A, due to the missing hills, if the BB hills are not affected by the double skips.

The percentage increase in yield of the exterior hills (A′) over the nearest unrelated hill (B) is shown in Table 9. The mean percentage increase of A′ over B for 1924 is 34.8 ±1.47, that for 1925 is 37.6 ±2.70, and that for 1926 is 39.9 ±3.71. It seems obvious that the difference between any two of these means is not mathematically significant. In other words, there is no difference in the effect of a double-hill skip whether one uses Smooth Rurals or Green Mountains as seed stock so far as the increase in yield of the exterior hill is a measure. The mean total percentage increase of A′ and of A over B, as given in Table 8, for 1924 is 37.8 ±1.79, that for 1925 is 50.7 ±3.53, and that for 1926 is 54.1 ±5.03. The difference between the sum for 1924 and that for 1925 is as significant as the difference between the sum of the means for 1925 and 1926, respectively. Since Smooth Rurals were used in 1924 and 1926 and Green Mountains in 1925, it is obvious that variety plays a minor rôle among the factors influencing the effect of missing hills. The most that can be said is that when large numbers are used two missing hills increase the yield of the adjacent pairs of hills from 75 to 100%.

Comparison by actual differences.—The difference in ounces of the yields of the exterior hill (A′) and the nearest unrelated hill (B) of the inside pair of hills (BB) was determined and the usual constants

TABLE 9.—*Percentage increase in yield of the exterior hill (A′) over the unrelated hill (B) determined by "percentage difference" method.*

Block No.	Average weight seed tuber in grams	n	Mean	Standard deviation	Precentage range
			1924		
1	152.0	88	42.3±3.52	48.9±2.49	—47.1 to +266.7
3		85	24.7±2.17	29.6±1.53	—58.3 to +100.0
1 and 3		173	33.7±2.13	41.5±1.50	
2	161.0	86	41.8±3.17	43.6±2.24	—31.1 to +191.7
4	170.5	86	30.2±2.41	33.2±1.71	—36.1 to +142.9
All 4 blocks	158.9	345	34.8±1.47	40.4±1.04	—58.3 to +266.7
			1925		
1	157.0	69	43.0±4.67	57.5±3.30	—63.6 to +212.5
3		61	43.0±6.78	78.5±4.79	—76.6 to +273.3
1 and 3		130	42.7±4.02	68.0±2.84	
2	168.0	58	39.2±7.01	79.1±4.95	—78.9 to +372.7
4	113.0	75	27.5±3.26	41.9±2.31	—55.0 to +147.0
All 4 blocks	148.7	263	37.6±2.70	64.9±1.91	—78.9 to +372.7
			1926		
1	155.0	80	38.7±5.63	74.7±3.98	—52.9 to +266.7
2	177.5	79	41.2±4.80	63.2±3.39	—56.7 to +208.0
Both blocks	166.2	159	39.9±3.71	69.3±2.62	—56.7 to +266.7

computed. The data appear in Table 10. The mean difference in ounces for 1924 was 11.3 ±0.45, that for 1925 was 7.3 ±0.59, and that for 1926 was 8.7 ±0.99. Again dividing each mean difference in ounces by its corresponding mean yield of B in ounces, the percentage increase due to the missing hills is determined. In Table 11 the percentage increase for 1924 is 29.3 ±0.01, that for 1925 is 23.5 ±0.02, and that for 1926 is 24.4 ±0.03. These three values are less than the corresponding percentage increases as determined by the "percentage difference" method, again pointing out the discrepancy between the results obtained by the two methods.

TABLE 10.—*Increase in ounces of the yield of the exterior hill (A′) over the unrelated hill (B) determined by "actual difference" method.*

Block No.	Average weight seed tuber in grams	n	Mean	Standard deviation	Range in ounces
			1924		
1	152.0	88	14.3±0.96	13.4±0.68	—14 to +48
3		85	7.8±0.78	10.6±0.55	—42 to +31
1 and 3		173	11.1±0.65	12.6±0.46	
2	161.0	86	12.8±0.92	12.6±0.65	—15 to +46
4	170.5	86	10.2±0.81	11.1±0.57	—20 to +38
All 4 blocks	158.9	345	11.3±0.45	12.3±0.32	—42 to +48
			1925		
1	157.0	69	7.7±0.92	11.3±0.65	—28 to +34
3		61	8.0±1.55	17.9±1.09	—39 to +41
1 and 3		130	7.8±0.88	14.8±0.62	
2	168.0	58	7.2±1.35	15.2±0.95	—32 to +41
4	113.0	75	6.7±0.97	12.4±0.68	—28 to +28
All 4 blocks	148.7	263	7.3±0.59	14.3±0.42	—39 to +41
			1926		
1	155.0	80	7.9±1.45	19.2±1.02	—27 to +49
2	177.5	79	9.5±1.36	17.9±0.96	—38 to +52
Both blocks	166.2	159	8.7±0.99	18.6±0.70	—38 to +52

Each interior member (A) of the outside pair of hills (A′A or AA′) was adjacent to an unrelated hill (B) of the inside pair of hills (BB). Student's method was used to analyze the data. The mean difference in ounces and the standard deviation with their errors and the odds are presented in Table 12. If A outyielded B the difference was considered plus, and if A yielded less than B the difference was considered minus. In all but four instances A yielded less than B. In Table 12 the mean difference in 1924 is found to be—0.5 ±0.38 ounce with the odds 1.68 to 1 that such a difference is due to chance alone. In 1925 the mean difference is—0.1 ±0.59 ounce with odds of less than 1 to 1. In 1926 the mean difference is—0.9 ±1.03 with odds of less than 1 to 1. Considering the data as a whole, one would conclude that there is no difference in yield between the interior hill (A) of the outside pair of hills (A′A) and the adjacent hill (B) of the inside pair of hills (BB) under conditions obtaining at the time of these investigations.

TABLE 11.—*Percentage increase in yield of the exterior hill (A′) over its unrelated neighboring hill (B) as determined by dividing the mean difference in ounces between A′ and B by the mean yield of B. Double-hill skip data.*

Block No.	n	Mean yield of B in ounces	Mean difference A′–B in ounces	Percentage difference
		1924		
1	88	39.8±0.69	14.3±0.96	35.9±0.02
3	85	37.7±0.77	7.8±0.78	20.7±0.02
1 and 3	173	38.8±0.51	11.1±0.65	28.6±0.02
2	86	35.8±0.61	12.8±0.92	35.8±0.03
4	86	40.9±0.64	10.2±0.81	24.9±0.02
All 4 blocks	345	38.6±0.34	11.3±0.45	29.3±0.01
		1925		
1	69	26.4±0.84	7.7±0.92	29.2±0.04
3	61	32.8±0.94	8.0±1.55	24.4±0.05
1 and 3	130	29.4±0.65	7.8±0.88	26.5±0.03
2	58	29.7±0.72	7.2±1.35	24.2±0.05
4	75	34.7±0.68	6.7±0.97	19.3±0.03
All 4 blocks	263	31.0±0.42	7.3±0.59	23.5±0.02
		1926		
1	80	37.3±0.94	7.9±1.45	21.2±0.04
2	79	34.2±0.74	9.5±1.36	27.8±0.04
Both blocks	159	35.7±0.62	8.7±0.99	24.4±0.03

TABLE 12.—*The difference between the yield of the interior hill (A) and the yield of the adjacent unrelated hill (B) in ounces. Student's method used.*

Block No.	Average weight seed tuber in grams	n	Mean	Standard deviation	Odds
			1924		
1	152.0	88	−1.0±0.80	11.1±0.56	1.46:1 (B)
3		85	+0.3±0.70	9.6±0.50	<1:1
1 and 3		173	−0.4±0.53	10.4±0.38	<1:1
2	161.0	86	+0.5±0.74	10.2±0.52	<1:1
4	170.5	86	−1.7±0.77	10.6±0.55	6.06:1 (B)
All 4 blocks	158.9	345	−0.5±0.38	10.4±0.27	1.68:1 (B)
			1925		
1	157.0	69	−0.1±0.97	12.0±0.69	1.01:1 (B)
3		61	+1.5±1.46	16.9±1.03	1.01:1 (A)
1 and 3		130	+0.7±0.86	14.6±0.61	<1:1
2	168.0	58	−1.2±1.20	13.5±0.85	<1:1
4	113.0	75	−0.6±1.12	14.4±0.79	<1:1
All 4 blocks	148.7	263	−0.1±0.59	14.3±0.42	<1:1
			1926		
1	155.0	80	−1.5±1.46	19.3±1.03	1.01:1 (B)
2	177.5	79	−0.2±1.46	19.3±1.04	<1:1
Both blocks	166.2	159	−0.9±1.03	19.3±0.73	<1:1

The question then arises, Is the yield of hill A increased by the double-hill skip or is it decreased by competition, due to the greater growth of A′? If one assumes that the BB hills are not affected by the double-hill skips in the adjoining rows (Fig. 1), then it would seem that A′ does have a depressing effect on A, because A yields slightly less than B. On the other hand, if B benefits from the double-hill skips in the adjoining rows then it would become necessary to find how great that increase is before one could draw any conclusions as to the behavior of the A hill. Some evidence bearing on this point was obtained by comparing the BB pair of hills with its adjacent CC pair of hills at the end of the row (Fig. 1). It would seem reasonable to assume that the CC hills derive no benefit from the double skips. Using Student's method again, it was found that the odds were 3 to 1 that the CC hills yielded more than the BB hills in 1924, in 1925 the odds were 2 to 1 that the BB hills yielded more than the CC hills, and in 1926 the odds were 40 to 1 that the BB hills outyielded the CC hills. These results are rather inconclusive as the odds indicate no significant difference in 1924 and 1925 and are just over the border line of significance in 1926. Certainly if the BB hills benefit from the double skips in the adjoining rows the increment cannot be very great. With this in mind and the fact that the mean difference in ounces between A and B was minus for all three years, it would seem safe to assume that the A hill derives no benefit from the double skip adjacent to its exterior mate A′.

The mean differences in ounces of the yield of A and B as given in Table 12 are so small, all less than—1, that one might conclude that A and B yield equally. If this be true, then the percentage difference in yield of A′ and A, as given in Table 6, should equal, at least approximately, the percentage difference in yield of A′ and B. The means as given in Table 6 are 34.1 ±1.13, 29.7 ±1.66, and 30.1 ±1.67 for 1924, 1925, and 1926, respectively. The means in Table 9 are 34.8 ±1.47, 37.6 ±2.70, and 39.9 ±3 71 for 1924, 1925, and 1926, respectively. The greatest difference is between the two means for 1926, namely, 9.8 ±4.07%. This difference is but 2.4 times its probable error with odds of about 8 to 1, or such a difference would occur once in nine times due to chance alone. This is further proof that there is no difference in the yield of A and B.

If one accepts the proofs offered above, how can the increase in yield of A over B as determined by the percentage method be explained? As given in Table 7, these mean percentage increases were 3.0 ±1.02, 13.1 ±2.28, and 14.2 ±3.40 for 1924, 1925, and 1926, respectively. Considering the mean percentage increase for 1925, it would seem that so great an increase as 13.1% should be reflected in the "actual difference" method by a value greater than—0.1 ±0.59 ounce. Thirteen and one-tenth per cent of the mean yield of B in 1925 would be 4.1 ounces, yet the mean difference between the yields of A and B as determined by the "actual difference" method was *minus* 0.1 ounce. The percentage increase in yield of A over B as calculated by the "percentage difference" method is open to serious question. Before using either method one should consider carefully which is the better measure of the true difference between A and B. It is probable that the discrepancy between the results obtained by the two methods is due, in part at least, to the use of percentage, which exaggerates the difference between two values, particularly if they are extreme differences.

Interpretation of the results as given in Table 7, without considering their disagreement with the results of the "actual difference" method, must lead to the conclusion that the A hill is increased in yield, in so far as hill B is a standard of comparison, because of the double-hill skip. On the other hand, interpretation of the data as given in Table 12 would lead to the conclusion that there is no increase in yield of hill A, in so far as hill B is a standard, due to the double skip. If there is any difference it is a decrease in yield. As these means are practically the same, *viz.*,—0.5 ±0.38,—0.1 ±0.59, and—0.9 ±1.03 for 1924, 1925, and 1926, respectively, it is evident that the Green Mountain and Rural varieties are equally affected. Again the situation arises in which two directly opposed conclusions may be drawn from the same data because of the different results obtained by the use of two methods of computation. It is extremely important, then, that one should use care in the interpretation of results derived by the use of percentages.

COMPARISON AND DISCUSSION OF THE TWO METHODS

In the comparison of the results obtained by the use of these two methods of computation of the same data, it is well to keep in mind that the "percentage difference" method involves the computation of the percentage difference for each pair of hills and that the "actual difference" method involves the computation of the difference in ounces for each pair of hills. The mean percentage difference by the former method is the mean of many percentages, while the mean percentage difference by the latter method is the relationship of the mean difference in ounces to the mean yield in ounces of the base hill. expressed in per cent.

It has been noted before in this paper that the use of percentage tends to exaggerate differences. In a pair of hills where A′ yields 30 ounces and A yields 20 ounces, the difference is 10 ounces and A′ yields 50% more than A. In another pair of hills, A′ yields 20 ounces and A yields 30 ounces and the difference is 10 ounces. In this instance A′ yields 33.3% *less* than A. If these two percentage values are added algebraically, their sum is +16.7%, or A′ yields 16.7% more than A because of the missing hill. Contrasting this result with what obtains under similar conditions using the "actual difference" method, one finds that the increase of 10 ounces of the first pair is exactly balanced by the decrease in yield of 10 ounces in the second pair, the difference in this case being zero and the conclusion would be that there is no effect of a missing hill. It does not seem probable that there would be no effect evidenced in the growth of a hill adjacent to a skip, yet in this example by the use of the "actual difference" method of calculation that is the conclusion one would have to make. On the other hand, it does not seem logical to say that there is a 16.7% increase due to the missing hill, as measured by the "percentage difference" method, when the difference between increase and decrease in yield in ounces is zero. The reason for this apparent discrepancy is, of course, due to the exaggeration of the true differences by the use of percentage.

The exaggeration by the use of percentage is even more marked when dealing with the extreme variates. On the other hand, using the "actual difference" method these extremes would affect the final result only in so far as their true value would affect it. Opening the 1924 record book of original data at random and looking for the first instance where the difference between A′ and A is greater than 100%, this is what is found. In Row 423, starting with hill No. 27, the data are as follows:

Hill No.	Yield in ounces		Difference in ounces	Percentage difference
	Hill A′	Hill A		
Skip	—	—	—	—
27–28	53	23	30	130.4
29–30	35	46	—11	—23.9
Skip	—	—	—	—
31–32	40	46	— 6	—13.0
33–34	40	50	—10	—20.0
Skip	—	—	—	—
		4 |165	—27	—56.9
		41.25	30	130.4
			4 |3.00	4 |73.5
			41.25 |.75	18.4
			1.8%	

These data illustrate quite well how the discrepancies between the results from the two methods are brought about. The one plus extreme variate overbalances three minus variates and the result is a positive percentage difference of 18.4. On the other hand, the mean difference in ounces is but 0.75. The percentage increase as determined by the "actual difference" method is 1.8. The "percentage difference" method indicates a percentage increase of A′ over A 10 times as great as that indicated by the "actual difference" method. This example is not one unusual case, many such instances occurring throughout the data for the three years. It is evident that it would take a large number of *minus* percentage differences, which obviously are in the minority and tend to be smaller, to balance one extreme *plus* percentage difference. This further emphasizes the great care one should exercise in analyzing data by use of percentage and the necessity of extreme caution in the interpretation of the results obtained.

It might be said that such extremes would not occur or that the two hills did not have an equal chance from the start, aside from the effect of the missing hill. The author marked for elimination from the data all those pairs of hills that showed a marked discrepancy in size and vigor at an early stage of growth. Aside from this it is impossible to eliminate other apparent inconsistencies. It is utterly impossible to say that above 150% or 200% the difference is due to accident or factors other than the effect of missing hills and that below that value all differences are due solely to the effect of the missing hills. With this in mind the author has included all cases in the computations as they occurred except the pairs marked for discard soon after the plants emerged.

Considering the discussion above, it would seem that the true measure of the effect of a missing hill is between the values obtained by the two methods of interpretation. If the range of variability is wide the "actual difference" method would probably give the more accurate value. If the range of variability in the percentage increase as determined for each pair of hills is narrow, then the "percentage difference" method would result in a figure approximating the true increase due to the missing hill. Referring to Table 13 it will be seen that the data agree with this theory quite well. In 1924 the increase as determined by the "actual difference" method is 23.0 ±0.01% and the "percentage difference" method indicates an increase of 27.0 ±0.84%, a difference of 4.0 ±0.84. The D over P. E. value is 4.76, indicating odds of 750 to 1, and the difference is significant. In 1925 the "actual difference" method and the "percentage difference" method indicate an increase of 17.8 ±0.01 and 25.0 ±1.22%, respectively. Their difference is 7.2 ±1.22 with a D over P. E. value of 5.90. The odds are greater than 10,000 to 1 and the difference is considered a significant one. In 1926 the percentage increase obtained by the "actual difference" method is 14.7 ±0.01, while that by the "percentage difference" method is 20.0 ±1.60. The difference is 5.3 ±1.60% with a D over P. E. value of 3.31, indicating that the odds are 38 to 1 and the difference is significant. Referring to Tables 3 and 4 it is found that the range between the minus and the plus extremes of the individual determinations of differences is greatest in 1925, less in 1924, and least in 1926. Correlating this fact with the odds given above, one finds that the wider the range or greater the spread of the variates around the mean, the greater the difference between the percentage increase values as determined by the two methods.

TABLE 13.—*Comparison of the mean percentage increase in yield of A′ over A, due to a single-hill skip as computed by two methods, "actual difference" and "percentage difference."*

	Actual difference		Percentage difference	
Block No.	Coefficient of variability	Mean percentage increase	Mean percentage increase	Coefficient of variability
		1924		
1	97.8± 6.42	26.2±0.01	31.1±1.75	103.5± 7.05
3	127.3±10.01	19.1±0.01	23.1±1.54	123.8± 9.53
1 and 3	112.8± 5.75	22.5±0.01	27.1±1.18	113.3± 5.80
2	112.8± 8.21	21.6±0.01	24.4±1.58	118.0± 8.88
4	106.7± 7.42	26.0±0.02	29.2±1.79	112.7± 8.15
2 and 4	109.5± 5.50	23.5±0.01	26.8±1.20	115.7± 6.05
All 4 blocks	111.1± 3.98	23.0±0.01	27.0±0.84	114.1± 4.16
		1925		
1	188.9±22.54	16.4±0.02	25.9±2.76	179.9±20.57
3	188.5±21.79	17.8±0.02	26.8±2.62	170.5±18.07
1 and 3	187.8±15.53	17.3±0.01	26.4±1.90	175.0±13.61
2	208.3±26.80	15.5±0.02	20.6±2.01	167.0±17.71
4	145.7±13.50	20.8±0.02	26.7±2.24	146.8±13.68
2 and 4	172.9±13.21	18.3±0.01	23.7±1.52	156.5±10.99
All 4 blocks	179.6±10.06	17.8±0.01	25.0±1.22	167.6± 8.85
		1926		
1	166.7±16.85	14.7±0.01	20.0±1.60	143.0±12.73

In corroboration of this statement, referring to Table 14, the means of percentage increases of A′ over B, as determined by the two methods of measuring the difference, differ by 5.5 ±1.47% in 1924. In 1925 the means are 23.5 ±0.02 and 37.6 ±2.70 with a difference of 14.1 ±2.70%. In 1926 the means are 24.4 ±0.03 and 39.9 ±3.71 with a difference of 15.5 ±3.71%. The odds are 85 to 1 for 1924, 2,400 to 1 for 1925, and 207 to 1 for 1926. The range of the "percentage difference" variates in 1924 is from —58.3 to +266.7%, that for 1925 from —78.9 to +372.7%, and that for 1926 from —56.7 to +266.7%. It is again evident that the wider the range of the individual determinations of percentage differences the greater the discrepancy between the end results obtained by the two methods, that is, the mean percentage increase in yield of A′ over B due to the missing hills.

TABLE 14.—*Comparison of percentage increase in yield of A′ over B due to double-hill skip as computed by the two methods, "actual difference" and "percentage difference."*

	Actual difference		Percentage difference	
Block No.	Coefficient of variability	Mean percentage increase	Mean percentage increase	Coefficient of variability
		1924		
1	93.7± 7.91	35.9±0.02	42.3±3.52	115.6±11.26
3	135.9±15.23	20.7±0.02	24.7±2.17	119.8±12.19
1 and 3	113.5± 7.78	28.6±0.02	33.7±2.13	123.1± 8.96
2	98.4± 8.67	35.8±0.03	41.8±3.17	104.3± 9.56
4	108.8±10.27	24.9±0.02	30.2±2.41	109.9±10.45
All 4 blocks	108.8± 5.13	29.3±0.01	34.8±1.47	116.1± 5.73
		1925		
1	146.8±19.42	29.2±0.04	43.0±4.67	133.7±16.42
3	223.7±45.33	24.4±0.05	43.0±6.78	182.6±30.88
1 and 3	189.7±22.72	26.5±0.03	42.7±4.02	159.3±16.42
2	211.1±41.62	24.2±0.05	39.2±7.01	201.8±38.21
4	185.1±28.56	19.3±0.03	27.5±3.26	152.4±19.94
All 4 blocks	195.9±16.97	23.5±0 02	37.6±2.70	172.6±13.39
		1926		
1	243.0±46.37	21.2±0.04	38.7±5.63	193.0±29.91
2	188.4±28.77	27.8±0.04	41.2±4.80	153.4±19.66
Both blocks	213.8±25.75	24.4±0.03	39.9±3.71	173.7±17.42

As further proof let us consider the range of the variates as set forth in Table 7. This table deals with the percentage difference in yield between A and B. The range of the variates in 1925 is from —82.0 to +275.0%, that for 1926 from —76.1 to +293.3%, and that for 1924 from —64.1 to +144.4%. The mean percentage increase is directly correlated with the spread of the variates. The greatest spread occurred in 1926 and the highest mean percentage increase, namely 14.2 ±3.40, is obtained in 1926. The least spread of the variates in 1924 is directly correlated with the lowest mean percentage increase of A over B, namely, 3.0 ±1.02. It will be recalled that in the previous discussion it was demonstrated that the "percentage difference" method results in values much higher than the facts would warrant. So again one finds that the wider the range of the individual variates the greater the difference in the results obtained by the "percentage difference" method and the "actual difference" method. The effect of missing hills as measured by the increase in yield of the adjacent hills is dependent on the method of measuring it. The results obtained by the two methods are brought together in Table 15 to facilitate comparison.

TABLE 15.—*Comparison of the resuls obtained by the two methods of computation, namely, the "percentage difference" and the "actual difference" methods.*

Year	n	Percentage difference	Actual difference	Difference	D/P. E.	Odds
		Increase in Yield of A′ over A due to Single-hill Skip				
1924	616	27.0±0.84	23.0±0.01	4.0±0.84	4.76	750:1
1925	540	25.0±1.22	17.8±0.01	7.2±1.22	5.90	13,332:1
1926	146	20.0±1.60	14.7±0.01	5.3±1.60	3.31	38:1
		Increase in Yield of A′ over B due to Double-hill Skip				
1924	345	34.8±1.47	29.3±0.01	5.5±1.47	3.74	85:1
1925	263	37.6±2.70	23.5±0.02	14.1±2.70	5.22	2,400:1
1926	159	39 9±3.71	24.4±0.03	15.5±3.71	4.18	207:1
		Increase in Yield of A over B due to Double-hill Skip				
1924	345	3.0±1.02	—1.3±0.01	4.3±1.02	4.22	225:1
1925	263	13 1±2.28	—0.3±0.02	13.4±2.28	5.88	12,666:1
1926	159	14.2±3.40	—2.5±0.03	16.7±3.40	4.91	1,070:1

It is evident that there is some danger in using the "percentage difference" method. Because of this it would seem that one should be extremely careful in the interpretation of data derived by the use of percentage. It seems to be particularly dangerous when considering any problem related to yield in the potato. Yield in the potato is affected by so many factors that it is a highly variable quantity. Using percentage exaggerates the extreme variates, producing a false mean. Using the actual differences in ounces the extreme variates are not given any greater weight than they are entitled to, which results in a true mean. It takes the same amount of fertility to increase the yield of a hill by 10 ounces, whether the hill would otherwise yield 20 or 40 ounces. Using percentages, however, the one would be a much greater apparent increase than the other. The true value of the effect of missing hills lies somewhere between the values as determined by the two different methods. It is probable that the result obtained by the "actual difference" method more nearly represents the true value than does that obtained by the "percentage difference" method of calculation.

FACTORS INFLUENCING EFFECT OF MISSING HILLS

There are several factors that might influence the effect of missing hills as evidenced in the increased yield of the adjacent hills. Among these are varietal differences, size of seed piece, and soil and climatic conditions. The first one to be considered is that of varietal differences.

INFLUENCE OF VARIETY

To orient the reader it might be well to reiterate here that Smooth Rural No. 9 seed stock was used in 1924 and 1926 and Green Mountain seed stock in 1925. Referring to Table 4, the mean difference in, ounces between the exterior hill (A′) and its interior mate (A) for 1924 was 8.1 ±0.24, that for 1925 was 5.4 ±0.28, and that for 1926 was 6.0 ±0.56. It is obvious that there is no significant difference between the mean for 1925 and that for 1926, yet Smooth Rurals were used one year and Green Mountains in the other. The difference between these two means is 0.6 ±0.63 ounce, the odds are less than 2 to 1, and so the difference is not significant. On the other hand, comparing the means for 1925 and 1924, one finds the difference to be 2.7 ±0.37 ounces. This difference is 7.3 times its probable error so the odds are greater than 10,000 to 1. This difference is significant. Comparing the means for 1924 and 1926, Smooth Rurals being used both years, the difference is 2.1 ±0.61 ounces. The odds are 49 to 1, and this difference is significant. This evidence would indicate that there is no correlation between variety and increase in yield of the adjacent hills due to a missing hill.

The double-hill skip study furnishes further evidence in support of this hypothesis. Referring to Table 9, the mean increase of A′ over B for 1924 is 34.8 ±1.47%, that for 1925 is 37.6 ±2.70%, and that for 1926 is 39.9 ±3.71%. The greatest difference between any two of these means is that between 1924 and 1926, 5.1 ±4.0%. This difference is not significant as the odds are less than 2 to 1. Referring to Table 10, the mean difference in ounces between A′ and B is found to be 11.34 ±0.45 for 1924, that for 1925 is 7.3 ±0.59, and that for 1926 is 8.7 ±0.99. The greatest difference here is that between the means for 1924 and 1925. This difference is 4.0 ±0.74 ounces and it is about 5.4 times its probable error. The odds are about 3,500 to 1 and the difference is significant. This would indicate that there was a difference between the Smooth Rurals and the Green Mountains. Considering the means for 1924 and 1926, the two years the Smooth Rurals were grown, the difference is 2.6 ±1.09 and the D over P. E. value is about 2.4. The odds are 8 to 1 and this difference is not significant. This would indicate that the Smooth Rurals reacted the same both years. Considering the difference in ounces between A and B as given in Table 12, one finds the means to be —0.5 ±0.38 for 1924, —0.1 ±0.59 for 1925, and

—0.9 ±1.03 for 1926. It is obvious that variety is not a factor in this consideration. The bulk of the evidence indicates that variety plays a minor rôle, if any, among the factors influencing the effect of missing hills.

INFLUENCE OF SIZE OF SEED PIECE

The size of seed piece might be a factor in this study of the effect of missing hills. Referring to Table 4, it will be noted that the smaller seed tubers were planted in blocks 1 and 3, rows 121 to 128 and 321 to 328, respectively, in 1924 and in 1925. Larger seed tubers were planted in blocks 2 and 4, rows 221 to 228 and 421 to 428, respectively, in both years. The mean difference in ounces between the yield of the exterior hill (A′) and that of its interior mate (A) for 1924 is 7.8 ±0.34 for blocks 1 and 3 and 8.4 ±0.35 for blocks 2 and 4. In 1925 the mean difference in yield between A′ and A for blocks 1 and 3 is 4.9 ±0.38 ounces and for blocks 2 and 4 it is 5.9 ±0.42 ounces. The difference between the two means in 1924 is 0.6 ±0.49 ounce and that for 1925 is 1.0 ±0.57 ounce. Obviously these differences are not significant. In other words, missing hills affect hills from different sized seed pieces to the same extent. As further proof that size of seed piece does not influence the amount of increase in yield due to the skip, consider the mean differences in ounces of blocks 1 and 3 for 1924, as given in Table 4. These two blocks were planted with seed tubers of the same size. Their means are 9.1 ±0.48 and 6.6 ±0.45 ounces, respectively, and the difference between them is 2.5 ±0.66 ounces. The D over P. E. value is 3.8 with odds of 95 to 1, or only once in 96 trials would such a difference be due to chance alone. Certainly, with as great a difference between blocks planted with seed tubers of the same size and no difference between blocks planted with seed tubers of different sizes, one would not be justified in attributing much influence to size of seed piece.

From the double-hill skip study data as shown in Table 6, it will be noted that in 1925 the mean percentage difference in yield between the exterior hill (A′) and its interior mate (A) for block 4 is 24.8 ±2.73 and that for block 2 is 29.3 ±2.99. The difference between these means is 4.5 ±4.05%. The odds are about 1 to 1 and the difference is not significant, yet there was a difference of 27.5 grams, or practically 1 ounce, in the size of seed piece planted. Apparently the size of seed piece had no influence on the effect of the missing hills. Referring to Table 6 again, the mean percentage increase in yield of A′ over A due to the double skip is 42.2 ±1.87 for the first block and 23.3 ±2.00 for the third block in 1924. The difference between these two means is 18.9 ±2.74%. This difference is about 6.9 times its probable error so that the odds are greater than 10,000 to 1 and the difference is significant. Again one finds a significant difference between means of blocks from the same sized seed piece and no difference between the means of blocks planted with different sized seed pieces. Apparently there are factors at work other than variety or size of seed piece which determine the magnitude of the effect of missing hills.

INFLUENCE OF SOIL AND CLIMATIC FACTORS

Among the environmental factors that might influence the effect of missing hills, probably the most influential factor is the weather. It is quite generally agreed that the weather is the greatest single factor in determining the size of the potato crop. The year 1924 developed a bumper crop in New York, as well as in most of the United States. This would indicate that the weather in 1924 was nearly ideal so far as the potato crop was concerned. In New York the critical months for the potato crop, so far as the weather is concerned, are July and August. Referring to Table 16, it will be noted that in 1924 rainfall was above normal up to October. In 1925 the rainfall was erratic, that in July was mostly in the form of heavy showers which ran off the surface and so was lost to the crop, while the latter part of August Ithaca experienced a severe drouth. This was accompanied by a heavy infestation of leafhoppers, with the result that the foliage died prematurely. All the vines were dead before the first killing frost in September. In 1926 the total rainfall was deficient throughout the spring and up to August. In substance then, 1924 was a good potato year and 1925 and 1926 provided poor growing conditions for the potato crop. Since rainfall was plentiful in 1924 and limiting in 1925 and 1926, the following hypotheses are suggested. The lack of moisture prevents the solution of additional fertility made available by the missing hills, or, secondly, lack of moisture limits the spread of the additional fertility that is in solution, or both. In other words, with the moisture supply limited the adjacent hills are unable to make the greatest possible use of the additional fertility because of missing hills and the use they do make of it as evidenced by increase in yield will be in direct proportion to the available moisture supply.

Referring to Table 10, the mean difference in ounces between the exterior hill (A′) and the nearest unrelated hill (B) for 1924 is 11.3 ±0.45, that for 1925 is 7.3 ±0.59, and that for 1926 is 8.7 ±0.99. These are directly correlated with the weather conditions, that is, in 1924 the greatest mean difference with the best growing season of the three, in 1926 the next greatest, and in 1925 the least difference

TABLE 16.—*Monthly rainfall for the growing season at Ithaca. Data from the U.S. Weather Bureau Station at Ithaca, N. Y.*

Month	1924	1925	1926	40-year average
April	3.95	2.84	1.84	2.47
May	3.19	2.07	1.92	3.47
June	2.70	4.87	3.00	3.63
July	4.37	5.71	2.71	3.50
August	3.30	2.11	4.05	3.35
September	6.83	4.01	4.23	3.07
October	0.23	2.74	3.21	2.90
Total	24.57	24.35	20.96	22.39

correlated with the poorest potato season of all three. Again, in Table 4, the mean difference in ounces between the exterior hill (A′) and its interior mate (A) is greatest for the good season of 1924 and smallest for the poor season of 1925. Their means are 8.1 ±0.24 and 5.4 ±0.28 ounces, respectively. The difference is 2.7 ±0.37 ounces. This difference is more than seven times its probable error, and the odds are more than 10,000 to 1 and it is significant. In Table 3, also, the mean percentage difference between A′ and A for block 1 is 31.1 ±1.75 and that for block 3 is 23.1 ±1.54. Their difference is 8.0 ±2.33% with a D over P. E. value of about 3.4. The odds are about 45 to 1 and the difference is significant. The third series in 1924 was planted on a clay knoll where growing conditions for the potato crop would be less favorable than with the other three series of that year. This is evidenced in the third block of the double-hill skip study in 1924. The mean percentage increase of A′ over A for block 1 in 1924, as given in Table 6, is 42.2 ±1.87 and that for block 3 is 23.3 ±2.00. Their difference, 18.9 ±2.74%, is about 6.9 times its probable error. The odds are greater than 10,000 to 1 and the difference is significant. It is evident, then, that soil and weather, particularly rainfall, have a marked influence on the magnitude of the effect of missing hills. If one were attempting to measure other factors, such as competition, by differences in yield, it would be necessary to take this fact into consideration. It would seem that one should be extremely careful in regard to conclusions drawn in experiments supposed to show presence or absence of competition in potatoes. In years when there is a shortage of available moisture there would be considerably less advantage accruing to a hill or row because of competition or lack of space than in years of plentiful moisture. Because of this fact it is difficult to prove whether or not competition exists.

Stewart (8) found competition existed in three-row blocks of potatoes in the wet season of 1922. He measured the effect by the increase in yield of the outside rows as compared with the center rows. The following year, a dry season and poor potato year, he was unable to demonstrate a difference in yield between the exterior and interior rows.

Musgrave (3, 4) found that high-yielding rows growing adjacent to check rows depressed the yield of the latter in a normal potato season. The following year, which proved to be a very poor potato season in New Jersey, he found no depression of check-row yields by high-yielding rows. Both of these investigators found that in dry seasons no competition could be demonstrated. Neither of them offered any real reason as to why the dry season should eliminate competition.

From the author's data, coupled with the observations of Stewart and Musgrave, it would seem safe to conclude that lack of moisture reduces competition in so far as competition is measured by an increase in yield. In competition studies with the potato, then, one should be extremely careful to have a random sample of seasons and soils, that is, the experiments should be conducted for several years and on different soils before drawing definite conclusions as to whether or not competition exists.

The striking thing in all studies as to the effect of missing hills is the wide variation in the figure "percentage increase." It would be utter folly to attempt to use a formula to correct for the loss due to missing hills in potato yield tests. One would never know at what point in the wide range of variation that particular missing hill should be located. One might conclude, then, that there is an increase in the yield of the adjacent hills due to a skip. In the case of one missing hill this increase is at least 40% and may be more. With a double-hill skip the yield of the adjacent hills is increased 50%, and possibly more, depending on seasonal and soil conditions.

As a general conclusion, the writer is convinced that in potato field trials of any sort less error will be made if the effect of missing hills is disregarded entirely. The chances are that the missing hill is due to a weakness of some sort, whether caused by a known disease or not. The strain or variety with this hill in it should be handicapped by the loss in yield due to the missing hill. It is likely to be eliminated sooner from further trials because its yield is cut down that much. On the other hand, if it is good enough in yield to outyield other strains despite this handicap, then it is worthy of further trial.

PLAT SIZE AND REPLICATION

In 1923, as part of a paper discussing analysis and interpretation of data obtained in comparative tests of potatoes, Myers and Perry

(5) present an incomplete report on size of plat and frequency of replication in relation to the probable error. Change in value of the coefficient of variability was used as a measure of the effect of change in size of plat and increase in number of replications. Considering replication, the authors found no significant difference in the coefficient of variability for two as contrasted with five replications. This condition is probably brought about by the use of too few plats in this study. The large probable errors would indicate a small number of variates. It is quite possible that the use of more plats would have resulted in a greater difference in the value of the coefficient of variability. What data they present would indicate that a single row plat of 25 hills replicated four times would give a fair degree of reliability.

Krantz (2), in a short paper on field plat technic, finds that increasing plat size decreases experimental error. He uses the standard deviation to measure the effect of change in plat size. The standard deviation decreases as the plat size is increased but at a much slower rate than theoretically expected.

Increase in number of replications reduces the standard deviation to a lower value and more rapidly than theoretically expected. In conclusion Krantz states that the data do not justify the use of rows more than two rods in length and that replication is more effective than increasing the length of the plat in reducing the probable error. He has used a large number of plats in his experiments but makes no statement as to methods employed.

In 1924, Westover (11) published a paper on the influence of plat size and replication on experimental error in field trials with potatoes. His results agree with those of Krantz in that the reduction of the standard deviation by increasing plat size is considerably less than theoretically expected. Again, considering the effect of replication, when the replicates are systematically distributed, Westover found that increasing the number of replications decreased the standard deviation to a lower value and more rapidly than theoretically expected. The data presented justify his conclusion that a single-row plat 40 feet long and replicated four times will give a fair degree of reliability in comparative field trials with potatoes.

METHODS

A blank experiment was used for the study of the effect of increasing plat size and of replication on experimental error. The average weight of the seed tubers was 125 ±15 grams. Each tuber was cut in half and the pieces planted in consecutive hills. The rows were 112 hills long and there were 30 rows in the plat. This arrangement made it possible to use 30 corresponding plats of any length from 1 to 168 feet. Each hill was dug separately and number and weight of tubers determined. The data presented are for one year only, 1926.

INVESTIGATION AND DISCUSSION

INCREASING SIZE OF PLAT

The effect on experimental error of increasing the length of plat may be measured in several ways. Among these are the decrease in the value of the standard deviation, the coefficient of variability, and the error of a single observation. The theoretical error of a single observation was computed by dividing the observed error by the square root of *n*, on the assumption that the error should decrease as the number of variates or size of sample is increased.

Corresponding plats 12 feet long were used in the first study. The mean yield in bushels per acre, the standard deviation, and the coefficient of variability with their probable errors, together with the error of a single observation both observed and theoretical, were computed for the different sized plats. These plats varied in length from 12 feet to 168 feet. The data are assembled in Table 17.

TABLE 17.—*The effect of increasing the length of single-row plats as evidenced by change in value of several constants.*

Figures are in bushels per acre and for corresponding 12-foot plats. n = 30.

Length of plat in feet	Mean bushels per acre	Standard deviation	Coefficient of variability	Error single observation	Theoretical error single observation
12	329.2±7.03	57.1±4.97	17.35±1.56	38.5	38.5
24	319.5±5.18	42.1±3.67	13.18±1.17	28.4	27.3
36	314.2±4.51	36.6±3.19	11.65±1.03	24.7	22.3
48	310.6±4.03	32.7±2.85	10.53±0.93	22.1	19.2
60	309.0±4.21	34.2±2.98	11.07±0.98	23.1	17.2
72	311.3±4.17	33.9±2.95	10.89±0.96	22.9	15.7
84	315.7±3.76	30.5±2.66	9.66±0.85	20.6	14.6
96	320.0±3.82	31.0±2.70	9.69±0.85	20.9	13.6
108	324.6±3.69	30.0±2.61	9.24±0.81	20.2	12.8
120	328.9±3.51	28.5±2.48	8.67±0.76	19.2	12.2
132	328.9±3.20	26.0±2.26	7.91±0.69	17.5	11.6
144	328.6±3.04	24.7±2.15	7.52±0.66	16.7	11.1
156	327.7±3.03	24.6±2.14	7.51±0.66	16.6	10.7
168	329.6±2.98	24.2±2.11	7.34±0.64	16.3	10.3

The experimental error decreases as the length of plat increases. The total decrease in value of the error of a single observation as determined for plats 12 feet long and that for plats 168 feet long is 22.2 The greatest change between any two different sized plats occurs when the plat size is increased from 12 feet to 24 feet. This decrease is 45.5% of the total reduction. Increasing the length of the plat to 36 feet results in a decrease in error equal to 16.7% of the total. Adding another unit of 12 feet reduces the error an additional 11.7%. In other words, increasing the length of the plat from 12 feet to 48 feet reduces the error of a single observation 73.9% of the total decrease brought about by increasing the length to 168 feet. Increasing the length of the plat by the addition of 10 more 12-foot units accounts for only 26.1% of the total decrease.

The observed and theoretical "errors of a single observation" do not agree as the observed error does not decrease as rapidly nor to as low a value as the theoretical error. The deviation of the observed from the theoretical is probably due for the most part to the small number of variates used. It is quite possible that if a larger population or greater number of plats could have been used there would have been closer agreement between the observed error of a single observation and that theoretically expected.

Considering the coefficient of variability as set forth in Table 17, no significant difference can be demonstrated between the value of *C* for plats 48 feet long and any longer plat up to and including plats 168 feet in length. Comparing plats 36 feet long with longer plats, one finds no significant difference in the value of *C* until plats 156 feet in length are used. The standard deviation of plats 36 feet long is not significantly different from that of any longer plat up to and including plats 168 feet in length. In other words, it is evident that the variability of single-row plats of potatoes, as measured by the coefficient of variability and the standard deviation, is not materially reduced by increasing their size beyond 36 feet in length. The optimum length probably lies somewhere between 36 and 48 feet. Consideration of these data would not justify the additional land and labor involved in the use of plats longer than 48 feet.

Another analysis was made to study the effect of increasing the size of plat. Instead of using corresponding plats all possible combinations not involving duplication of plats were made. For instance, in doubling the length of plat, the average yield of each pair of adjacent (end to end) plats was determined. The average of each three adjacent plats was used as the yield of a plat 36 feet long. This process was carried on till plats 84 feet long were formed. The data are given in Table 18.

The difference in value of the error of a single observation for plats 12 feet long and that of plats 84 feet long is 13.8. Increasing the length of a plat from 12 feet to 24 feet resulted in 56.5% of this decrease. A subsequent decrease of 23.9% accompanies the increase in plat size from 24 feet to 36 feet. Increasing the plat from 12 feet to 36 feet decreased the error of a single observation by 80.4%. Little is to be gained by further increases in length of plat. The values of the error of a single observation determined for corresponding plats, as given in Table 17, agree quite closely with those for all possible combinations as set forth in Table 18.

Considering the standard deviation and the coefficient of variability in Table 18, no significant differences can be demonstrated between the values of these constants for plats 36 feet long and for any other length of plat up to 84 feet. These data again point out the fact that the reduction in experimental error brought about by using plats longer than 36 feet is not sufficiently great to warrant the use of the additional land and labor.

TABLE 18.—*The effect of increasing the length of single-row plats as evidenced by change in value of several constants.*

Length of plat in feet	n	Mean bushels per acre	Standard deviation	Coefficient of variability	Error single observation	Theoretical error single observation
12	420	329.5±1.70	51.6±1.20	15.66±0.37	34.8	34.8
24	210	329.6±1.87	40.1±1.32	12.17±0.41	27.0	24.7
36	150	329.5±1.93	35.1±1.37	10.65±0.42	23.7	20.1
48	120	332.2±2.14	34.8±1.52	10.48±0.46	23.5	17.4
60	90	331.3±2.40	33.8±1.70	10.20±0.52	22.8	15.6
72	60	328.4±2.97	34.1±2.10	10.38±0.65	23.0	14.2
84	60	330.0±2.71	31.1±1.91	9.42±0.59	21.0	13.2

REPLICATION

It was demonstrated in the discussion of the effect of increase in length of plat that a single-row plat 36 feet in length was probably the most desirable size of plat, considering both experimental accuracy and expediency. With this in mind, the 30 rows were divided into plats 36 feet long for the replication study. Two methods of analyzing the data were used; the first, that of replicating corresponding plats, the second, that of systematically distributing the replicates throughout the plat. Replication as used in this paper means a repetition of an original. If one replication were mentioned that would mean two plats, the original and its replicate. If three replications were mentioned that would mean four plats, the original and its three replicates.

The number of replications varied from 0 to 6. In the first analysis, for one replication, plats numbered 1 to 1 and 16 to 1; 2 to 1 and 17 to 1; 1 to 2 and 16 to 2, etc., were paired. For two replications, plats numbered 1 to 1, 11 to 1, and 21 to 1; 2 to 1, 12 to 1, and 22 to 1; 11 to 2, and 21 to 2, etc., were combined. This process was carried out for three, four, five, and six replications. It will readily be seen that as the number of replications increases the corresponding replicates are located nearer each other. This condition would tend to nullify the effect of replication as measured by reduction in experimental error, since it is obvious that the closer together the replicates are located the more nearly uniform in yield they are likely to be and therefore less variability will be noted. This is brought out by the data in Table 19.

TABLE 19.—*The effect of replication as evidenced by change in value of several constants. Replicates are corresponding 36-foot plats.*

Number of replications	n	Mean bushels per acre	Standard deviation	Coefficient of variability	Error single observation	Theoretical error single observation
0	150	329.2±1.99	36.1±1.41	10.97±0.43	24.3	24.3
1	75	329.2±2.11	27.1±1.49	8.23±0.46	18.3	17.2
2	50	329.3±1.89	19.8±1.34	6.01±0.41	13.4	14.0
3	35	331.3±2.25	19.7±1.59	5.95±0.48	13.3	12.1
4	30	329.4±2.27	18.4±1.60	5.59±0.49	12.4	10.9
5	25	328.6±2.27	16.8±1.60	5.11±0.49	11.3	9.9
6	20	330.9±2.67	17.7±1.89	5.35±0.57	11.9	9.2

It will be noted that the error of a single observation was decreased markedly by one replication and still further reduced by using two replications, but that for two to six replications there is very little change. This is to be expected as the replicates were nearer each other as the number of replications increased. There is a total decrease of 13.0 in the error of a single observation as computed for plats replicated from 0 to 6 times, and 83.8% of this decrease is accomplished by two replications (three plats). Considering the standard deviation and coefficient of variability, it is found that no significant differences can be demonstrated between the values for two replications and those for a greater number up to and including six replications. From these data one would conclude that three replications are sufficient to insure a reasonable degree of reliability in the results obtained from a field trial.

When the replicates are systematically distributed one finds a little closer agreement with theory and a greater effect of replication. This is to be expected as these plats are farther apart and hence more likely to be variable. Obviously the greater the number of these plats that are averaged the more the variations between them will be smoothed out. This will be reflected in a smaller standard deviation which in turn will decrease the error of a single observation.

In Table 20 it is of interest to note that the value for the error of a single observation when replicates are systematically distributed decreases more rapidly, more consistently, and to a lower point than in the case of corresponding plats as seen in Table 19. In the former instance the observed error is less than the theoretical error, while in the latter the reverse is true. It is also to be noted that the probable errors of the mean, standard deviation, and coefficient of variability decrease as the number of replications increases. This is influenced by the consistent decrease in the value of the standard deviation. Such a result would indicate that the more nearly random the distribution of a given number of replicates the more accurate will be the results.

TABLE 20.—*The effect of replication as evidenced by the change in value of several constants. Random distribution of replicates.*

Number of replications	n	Mean bushels per acre	Standard deviation	Coefficient of variability	Error single observation	Theoretical error single observation
0	150	329.2±1.99	36.1±1.41	10.97±0.43	24.3	24.3
1	73	328.4±1.88	23.8±1.33	7.25±0.41	16.1	17.2
2	48	328.9±1.79	18.4±1.27	5.59±0.39	12.4	14.0
3	37	329.1±1.64	14.8±1.16	4.50±0.35	10.0	12.1
4	28	328.1±1.80	14.1±1.27	4.30±0.39	9.5	10.9
5	23	328.9±1.81	12.9±1.28	3.92±0.39	8.7	9.9
6	18	330.9±1.78	11.2±1.26	3.38±0.38	7.6	9.2

The total decrease in value of the error of a single observation, as set forth in Table 20, is 16.7. Increasing from 0 to 1 replication accounts for 49.1% of this decrease. An additional 22.1% is accounted for by increasing to 2 replications. Increasing the number of replications from 0 to 3 results in 85.6% of the total decrease. This would indicate that probably three and certainly four replications of a plat 36 feet long are sufficient to furnish a reasonable degree of reliability. Furthermore, no significant difference can be found between the values for the standard deviation and the coefficient of variability, respectively, for three replications and any greater number up to six replications. This is additional evidence that three replications are sufficient for a reasonable degree of accuracy, and that four replications would certainly give reliable results.

Replication is more effective than increasing plat size as a means of reducing experimental error. Increasing the size of plat from 36 feet to 72 feet reduces the error of a single observation 8.1%. Using the same area of land but replicating the plats once instead of doubling their length reduces the error 46.6%. Increasing the length from 36 feet to 108 feet reduces the error 20.3%. Using the same area again, but replicating the plats twice, reduces the error 84.8%. It is evident then that with a given area of land one should sacrifice size of plat rather than replication.

In conclusion it may be stated that, under conditions similar to those obtaining at the time these experiments were conducted, single-row plats of about 36 feet in length and replicated four times will give a reasonable degree of accuracy in comparative field trials with potatoes.

SUMMARY

The difference in yield between adjacent hills planted with halves of the same seed tuber is approximately zero.

The yield of the two hills adjacent to a single-hill skip is increased at least 40% and possibly more because of the skip. The yield of the two pairs of hills adjacent to a double-hill skip is increased at least 75% and possibly more because of the double skip. The effect of missing hills is markedly influenced by soil and climatic conditions. Variety and size of seed piece play a minor rôle in this respect.

The data from the missing hill studies were used to point out the dangers involved in the use of percentage in the calculation of statistics from such data. It was demonstrated that computation by percentage resulted in values much higher than by the "actual difference" method. This discrepancy in results is due to the exaggeration of values when using percentage, particularly when dealing with the extreme variates.

With respect to size of plat and number of replications, it seems safe to conclude that a single-row plat of about 36 feet in length replicated four times insures a reasonable degree of accuracy for comparative field trials with potatoes

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CORRELATION BETWEEN YIELDING ABILITY, REACTION TO CERTAIN DISEASES, AND OTHER CHARACTERS OF SPRING AND WINTER WHEATS IN ROD-ROW TRIALS[1]

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The reason why certain varieties perform more satisfactorily than others is of great importance to the plant breeder. Such information furnishes the basis for a logical plan for the improvement of the crop. At present it is not possible by plant physiological methods alone to obtain all necessary information regarding the reasons for differential responses of various important varieties. By growing the varieties in a field trial, however, it is possible to obtain comparable data on such characters as yielding ability, time of maturity, reaction to prevalent diseases, and certain morphological characters. By biometrical methods the data can be analyzed for the purpose of learning the relative importance of various characters in their influence on yielding ability.

A series of rod-row trials were made at the Waseca branch station in 1926. Conditions were so favorable for the study that it was planned to determine, by means of correlation coefficients, the importance of mode of reaction to various diseases, together with agronomic and botanical character differences in their relation to yielding ability.

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RESULTS OF SPRING WHEAT STUDIES

Most of the lines in these spring wheat trials were obtained from crosses. These lines are those which have been selected previously during the segregating generations. The lines placed in the rod-row trials appeared of most promise and were homozygous also for all important characters. The primary purpose of making the crosses was to obtain stem-rust-resistant sorts which were desirable agronomically. Eight North Dakota selections obtained from hybrids which had Kota as one parent, and the Wisconsin selection, Progress, were included. Of the 50 varieties or selections grown in the trials, 24 had Kota as one parent. These all proved resistant to stem rust and they had been selected previously for rust resistance in the rust breeding nurseries. Fifteen hybrids were purified crosses of Marquis with Kanred. These were made for the purpose of obtaining spring wheats which were homozygous for the Kanred type of immunity from several physiologic forms of stem rust. Several of these hybrids were highly susceptible to at least some of the physiologic forms responsible for the rust infection obtained in the Waseca plats. Seven purified hybrids of crosses between Marquis, which is scab susceptible, with Preston and Bluestem, which are scab resistant, were known to be susceptible to stem rust. They were produced in an attempt to obtain lines as resistant to scab as Preston and Bluestem and as desirable as Marquis. The variety Marquillo obtained from a cross of Iumillo durum with Marquis was included. It is usually rust resistant at Waseca but not, as a rule, particularly desirable for this section It performs rather satisfactorily, however, in the Red River Valley.

The various parental varieties and hybrids were selected previously for other characters, such as vigorous growth, strength of straw, and desirable seed. These 50 varieties represented a selected group of most promise in comparison with other less promising types.

Each of the lines was grown in three systematically distributed plats of three rows each and the central row was harvested for the yield trials. Separate determinations for each character were made for each plat and the summarized data, which represent in each case an average of three determinations, are presented in Table 1.

Certain features which can be observed by an examination of the data in Table 1 are of considerable interest. The Kota-Marquis crosses proved resistant to stem rust. Several of them, however, were very susceptible to leaf rust. The leaf rust infection was severe

TABLE 1.—*Data from spring wheat rod-row trials at Waseca, 1926.*

Variety	N. S. N.	Date of heading in June	Stem rust[a]	Leaf rust	Bearded or awnless[b]	Black chaff[c]	Height of plant, inches	Plumpness of grain	Yield per acre, bushels
			%	%				%	
Marquis x Preston..........	II-15-8	26	42 S	12	A	O	36	73	21.0
Marquis x Preston	-13	26	40 S	17	A	O	36	78	22.2
Marquis x Preston	-16	28	37 S	17	A	Tr	37	78	17.9
Marquis x Preston...... ..	-24	26	45 S	13	B	O	34	78	16.6
Marquis x Bluestem	II-15-39	28	30 S	3	A	Tr	39	70	20.7
Marquis x Bluestem........	-41	27	33 S	8	A	L	39	67	21.3
Marquis...	Check	26	38 S	5	A	Tr	35	72	17.1
Kota...............	Check	27	2 R	43	B	L-	35	77	19.0
Ceres.....................	N. D. 1658	26	5 SR	13	B	L-	32	80	21.9
Progress	C. I. 6902	24	10 R	50	B	Tr	34	87	20.2
Marquis x Kanred..........	B2-5	26	25 SR	42	B	O	34	70	18.2
Reliance............... ..	B8-11	27	42 S	20	B	O	34	68	15.9
Marquis x Kanred	B9-11	27	42 S	17	B	O	32	70	19.9
Marquis x Kanred	II-17-14	27	37 S	20	B	Tr	33	75	19.4
Marquis x Kanred..........	-16	28	23 SR-S	22	B	O	35	80	18.3
Marquis x Kanred..	-22	27	12 SR	57	A	Tr	32	53	14.9
Marquis x Kanred..........	-25	30	22 SR	47	B	Tr	36	73	16.3
Marquis x Kanred...	-28	30	28 SR	43	B	Tr	36	77	16.6
Marquis x Kanred..........	-36	30	28 S	30	B	O	36	75	17.4
Marquis x Kanred..........	-37	26	37 SR-S	32	A	L-	33	72	17.8
Marquis x Kanred....... ..	-40	26	35 SR-S	15	B	O	34	77	20.1
Marquis x Kanred....	-43	27	48 S	10	B	Tr	33	63	16.5
Marquis x Kanred..........	-45	28	33 SR-S	7	B	O	36	75	19.3
Marquis x Kanred...... .. .	II-18-8	26	38 S	20	B	O	34	72	18.3
Marquis x Kanred..........	-44	27	47 S	13	B	O	33	77	19.1

Kota x Ruby	II–19–48	27	0.5 R	20	B	L–	34	72	17.3
Kota x Ruby	–49	23	0.5 R	50	B	L–	33	67	17.2
Kota x Ruby	–55	23	1 R	40	B	Tr	35	78	18.4
Marquis x Kota	II–19–9	27	0.5 R	35	B	H–	35	80	18.9
Marquis x Kota	–11	26	0.5 R	30	B	L–	34	87	21.3
Marquis x Kota	–46	25	0.5 R	37	B	L–	33	78	20.7
Marquis x Kota	–47	26	2 R	7	B	L	34	75	20.5
Marquis x Kota	–51	26	1 R	33	B	L	34	78	19.8
Marquis x Kota	–53	25	1 R	30	A	L–	33	57	15.5
Marquis x Kota	–57	25	3 R	30	B	L	32	75	17.4
N. D. 1656	Bulk	24	2 R	8	B	M–	34	83	22.3
N. D. 1656 Selection	1656–47	26	1 R	20	B	M–	33	78	17.0
N. D. 1656 Selection	–81	26	0.5 R	3	B	M–	33	80	19.1
N. D. 1656 Selection	–83	25	5 R	28	B	L	33	78	20.2
Marquis x Kota	1657–139	26	0.5 R	10	B	L	34	83	24.4
N. D. 1656 Selection	1656–84	26	1 R	18	B	M	34	80	22.2
N. D. 1656 Selection	–97	27	0.5 R	15	B	M+	35	73	21.7
Kota Natural Cross	II–18–16	29	5 R	47	B	L+	38	83	18.0
Kota Natural Cross	–17	29	1 R	57	B	L–	36	73	18.5
Kota Natural Cross	–28	28	1 R	50	B	L–	36	80	20.2
Kota Natural Cross	–33	29	0.5 R	52	B	L+	37	78	18.4
Kota Natural Cross	–37	30	0.5 R	30	B	M	38	83	18.2
Kota Natural Cross	–56	28	0.5 R	42	B	L+	36	77	15.9
Kota Natural Cross	II–19–2	29	4 R	53	B	M–	34	70	16.6
Marquillo	II–15–44	22	10 R–SR	20	A	Tr	30	72	14.1

[a] R = resistant, S = susceptible, SR = semi-resistant.

[b] B = bearded, A = awnless.

[c] O = no infection, Tr = trace, L = light, M = medium, H = heavy.

and the opportunity was good, therefore, to study its importance in relation to yielding ability. Marquis is susceptible to stem rust, while Kota is resistant. These two varieties react in the opposite way to leaf rust. The hybrids were selected during the segregating generations for resistance to stem rust, as has been mentioned, and for resistance to leaf rust when the degree of infection made it possible. Leaf rust is not, as a rule, a serious menace to the bread wheats commonly grown in Minnesota. Perhaps the reason for this is that Marquis and other common wheats like Preston and Bluestem are usually resistant to leaf rust when grown in the Northwest spring wheat area. The Marquis x Preston and Marquis x Bluestem crosses, grown in this trial, were highly resistant to leaf rust. Several of the Kanred x Marquis crosses were susceptible to leaf rust, others were resistant.

The varieties of small grains grown in a locality are frequently those which are resistant to diseases prevalent in the locality. It often happens, however, in breeding for resistance to a certain disease that susceptibility to an equally important disease or to some disease not commonly prevalent in the locality is obtained. An excellent illustration of such a result was observed in the Kota crosses. Kota is resistant to stem rust, susceptible to leaf rust, and somewhat susceptible to black chaff. All of the Kota hybrids in these trials proved as susceptible to black chaff or more so than the Kota parent. Such an unfortunate result illustrates the necessity of considering all possible factors in any breeding project and makes plain the reason that it is desirable to have accurate information regarding the importance of various characters.

Most of the data presented in Table 1 are easily understood. The stem rust note was taken on the basis of percentage of infection and type of infection. Very small pustules, as well as long linear ones, are considered to represent high resistance (R), while large, healthy pustules indicate complete susceptibility (S). A less sharply defined intermediate group is designated as semi-resistant (SR). The infection percentage of S is multiplied by 1, that of SR by 0.66, and R by 0.33 to obtain a more comparable numerical measure of rust reaction. With leaf rust it is not possible easily to separate types of infection in the field, and the percentage note therefore is used directly. B stands for bearded and A stands for awnless, or more properly in these studies for tip-awned spikes. The data on black chaff were taken as O, no infection; Tr, trace; L, light; M, medium; and H, heavy. The classes were further subdivided by the use of minus (—) or plus signs (+) to indicate intermediate degrees.

Percentage plumpness of seed is taken on the basis of 100 as the standard for absence of shriveling of the seed.

Simple product moment coefficients of correlation, correlation ratios, and Blakeman's test of linearity are given in Table 2. Several of the correlation surfaces apparently deviate quite widely from linearity. The correlation ratio was calculated by the usual formula and the recent correction given by Pearson[3] was not used. Taking one case in which η^2—r^2 divided by its probable error was 4 and applying the correction to the correlation ratio, there was a marked reduction in the size of the correlation ratio and the calculated value of η^2—r^2 divided by its probable error was reduced from 4 to 2.6. By an examination of the correlation surfaces for the cases where η^2—r^2 divided by its probable error was large, it was apparent that one to several extreme variates, in classes in which there were few individuals, were chiefly responsible for the apparent deviations from linearity. Except for the studies of black chaff in relation to other characters, it is believed that the correlation coefficient more

TABLE 2.—*Simple product moment correlation coefficients, correlation ratios, and Blakeman's test of linearity of regression, rod-row trials of spring wheat at Waseca, 1926.*

Characters correlated	r	η	$\frac{\eta^2-r^2}{\text{P. E.}\ \eta^2-r^2}$
Date heading and percentage stem rust	+0.1457	0.4414	2.6
Date heading and percentage leaf rust	+0.2068	0.4158	2.2
Date heading and plant height	+0.6181	0.7372	2.3
Date heading and yield	—0.1298	0.5446	3.8
Stem rust and leaf rust	—0.4704	0.5590	1.7
Stem rust and plant height	+0.0999	0.5529	4.0
Stem rust and yield	—0.0785	0.5454	4.0
Leaf rust and plant height	+0.0589	0.5259	3.8
Leaf rust and yield	—0.3704	0.6241	3.3
Plant height and yield	+0.1815	0.4745	2.8
Percentage plumpness and stem rust	—0.2767	0.5540	3.2
Percentage plumpness and leaf rust	—0.0535	0.4316	2.8
Percentage plumpness and yield	+0.5101	0.6839	2.8
Percentage plumpness and date heading	+0.0168	0.5446	4.1
Percentage plumpness and plant height	+0.1969	0.5245	3.3
Date heading and black chaff		0.3865	
Yield and black chaff		0.4967	
Stem rust and black chaff		0.7492	
Leaf rust and black chaff		0.5417	
Plant height and black chaff		0.4301	

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[3] PEARSON, KARL. On the correction necessary to the correlation ratio. Biom., 14:412–417. 1923.

nearly expresses the degree of correlation in these studies than the correlation ratio.

Leaf rust and yield gave a correlation coefficient of —0.3704, stem rust and yield a value of —0.0785, and leaf rust and stem rust a correlation of —0.4704. It is apparent that the stem-rust-resistant lines are more usually susceptible to leaf rust than the stem-rust-susceptible lines. Percentage plumpness of grain was more strongly correlated with yield than any other character. The calculated coefficient of correlation was +0.5101.

For the purpose of learning the true relationship between the various characters, partial correlation coefficients were computed. The partial correlation coefficient gives the direct relation between two variables holding constant the effect of other variables considered. All characters considered are given in Table 3, except percentage plumpness of grain. Holding constant date heading, height of plant, and yield, the correlation between stem and leaf rust becomes $r_{BC.ADH}$ = —0.5789 ±0.0634, where A = height of plant, B = percentage stem rust, C = percentage leaf rust, D = height of plant in inches, and H = yield in bushels per acre.

TABLE 3.—*Comparison of simple product moment coefficients and partial correlations in spring wheat.*

Product moment correlations		Partial	Correlation
Characters correlated	Correlation coefficient	correlations[a]	coefficient
Date heading and stem rust.	+0.1457±0.0934	$r_{AB.CDH}$ =	+0.1737±0.0925
Date heading and leaf rust ..	+0.2068±0.0913	$r_{AC.BDH}$ =	+0.1883±0.0920
Date heading and plant height	+0.6181±0.0590	$r_{AD.BCH}$ =	+0.6273±0.0579
Stem rust and leaf rust......	—0.4704±0.0743	$r_{BC.ADH}$ =	—0.5789±0.0634
Stem rust and plant height...	+0.0999±0.0944	$r_{BD.ACH}$ =	+0.0666±0.0950
Leaf rust and plant height...	+0.0589±0.0951	$r_{CD.ABH}$ =	+0.0655±0.0950
Yield and date heading......	—0.1298±0.0938	$r_{HA.BCD}$ =	—0.1845±0.0921
Yield and stem rust.........	—0.0785±0.0948	$r_{HB.ACD}$ =	—0.3090±0.0863
Yield and leaf rust.....	—0.3704±0.0823	$r_{HC.ABD}$ =	—0.4467±0.0763
Yield and plant height	+0.1815±0.0922	$r_{HD.ABC}$ =	+0.3302±0.0850

[a] A = date heading, B = percentage stem rust, C = percentage leaf rust, D = height of plant in inches, and H = average yield in bushels per acre.

Of most interest are the factors which are correlated with yield. The partial correlation coefficients are as follows:

Yield and date heading ... . $r_{HA.BCD}$ = —0.1845±0.0921
Yield and stem rust.... ... ...$r_{HB.ACD}$ = —0.3090±0.0863
Yield and leaf rust.. . . . . $r_{HC.ABD}$ = —0.4467±0.0763
Yield and plant height..... ... . $r_{HD.ABC}$ = +0.3302±0.0850

The simple product moment coefficient of correlation for yield and stem rust was —0.0785 ±0.0948, while the partial correlation of stem rust and yield with plant height, leaf rust, and date heading held constant was —0.3090 ±0.0863.

Height of plant in inches is positively correlated with yielding ability to the extent of $r_{HD.ABC} = +0.3302 \pm 0.0850$ when leaf rust, stem rust, and date heading are held constant.

The total effect of all four factors in relation to yielding ability was computed, $R_{H.ABCD} = 0.5524$. Substituting this value in the equation $100 \text{ x } 1 - \sqrt{1-r^2}$, a value of 16.64% is obtained, or the extent to which total variation in yielding ability is dependent upon these four factors. It is apparent that much of the variation is due to unknown causes, although in these and other plant breeding trials a considerable part of the variability is a function of the method of test, in other words, a result of soil heterogeneity or other non-controllable errors.

Simple product moment and partial correlation coefficients are given in Table 4 for the four variables percentage stem rust, percentage leaf rust, percentage plumpness of grain, and yield in bushels per acre. Percentage plumpness of grain gave a simple product moment coefficient of relationship with yield of +0.5105 ±0.0706 which shows the importance of this character in relation to yield. This is what should be expected because severe shriveling of the seed directly modifies yield.

Stem rust and plumpness of grain are negatively correlated to the extent of —0.2767 ±0.0881.

TABLE 4.—*Comparison of simple product moment coefficients and partial correlations in spring wheat.*

Product moment correlations		Partial correlations[a]		Correlation coefficient
Characters correlated	Correlation coefficient			
Stem rust and leaf rust . . .	—0.4704±0.0743	$r_{BC.KH}$	=	—0.5201±0.0696
Stem rust and plumpness. . . .	—0.2767±0.0881	$r_{BK.CH}$	=	—0.2224±0.0907
Leaf rust and plumpness.	—0.0535±0.0951	$r_{CK.BH}$	=	+0.0255±0.0953
Yield and stem rust	—0.0785±0.0948	$r_{HB.CK}$	=	—0.1596±0.0929
Yield and leaf rust.	—0.3704±0.0823	$r_{HC.BK}$	=	—0.4198±0.0785
Yield and plumpness	+0.5101±0.0706	$r_{HK.BC}$	=	+0.4733±0.0740

[a] B = percentage infection stem rust, C = percentage infection leaf rust, K = percentage plumpness of grain, and H = yield in bushels per acre.

The multiple correlation $R_{H.BCK}$, or the correlation of stem rust, leaf rust, and percentage plumpness of grain in relation to yield was 0.6278 which indicates that 22.06% of the total variability of yield was dependent upon these three factors. The total effect of all factors considered in relation to yield or $R_{H.ABCDK}$ was 0.6592. On this basis 24.8% of the total variability in yield is accounted for.

RESULTS OF WINTER WHEAT STUDIES

The winter wheats were produced primarily for the purpose of obtaining winter-hardy varieties which are of desirable agronomic type and which produce grain of good quality. Minturki and Minhardi were produced at Minnesota from a cross of Odessa, a late-maturing winter-hardy variety, and Turkey. These two varieties are as early maturing as Turkey when grown in Minnesota and as winter-hardy or more so than Odessa. Minturki has proved the best yielder, although Minhardi has yielded nearly as well at University Farm. Minard is a selection from a cross in which Turkey was one of the parents. It produces very corneous seed, as a rule, and is rather winter-hardy. Turkey, Minn. 1488, was used as the Turkey parent in the crosses here reported. It is a variety produced from an individual plant selection and is one of the most winter-hardy Turkey varieties yet obtained.

Minturki is rather resistant to stem rust and in southern Minnesota has not, as a rule, been injured appreciably by rust even when other varieties were severely injured. It is not known from which parent this resistance was obtained. While no data are given for Minhardi in Table 5, it has always been highly susceptible in Minnesota to stem rust infection. One plat of Minhardi was grown, but due to an error the two other plats which were supposed to have been sown to Minhardi were sown to Minturki, consequently Minhardi was not included in the calculations. Data for other varieties are from an average of at least three plats in all cases. The single plat of Minhardi was severely injured by stem rust. This makes certain of the crosses of Minhardi with Minard of considerable interest. The rust infection of several of these was clearly of the SR type and 11-20-6 showed only 12% of infection by stem rust of the SR type, while Minard showed 32% S infection. Recombination of genetic factors evidently occurs in these winter wheat crosses whereby a cross of two susceptible varieties leads to the production of some semi-resistant types.

All of the winter wheats were apparently rather susceptible to leaf rust, although some were more severely injured than others. While all of the varieties and selections were rather winter hardy, some were more severely injured than others. As a result of a dry period early in the spring the winter wheats did not yield as well as they ordinarily do.

Simple product moment coefficients of correlation, correlation ratios, and Blakeman's test of linearity are given in Table 6. There is good evidence of approximate linearity of relationship and consequently the correlation coefficient is the best measure of correlation.

TABLE 5.—*Data on winter wheat varieties grown at Waseca, rod-row trials, 1926.*

Variety	N. S. N.	Date of heading in June	Stem rust[a]	Leaf rust	Bearded or awnless[b]	Height of plant, inches	Winter injury	Plumpness, grain	Yield per acre, bushels
			%	%			%	%	
Turkey x Minhardi.........	II–19–49	27	37 S	32	B	32	12	70	9.5
Turkey x Minhardi.........	–50	26	35 S	30	B	32	12	70	11.0
Turkey x Minhardi.........	–29	25	42 S	39	A	28	6	57	9.5
Turkey x Minhardi.........	–31	23	40 S	33	B	31	7	73	14.9
Turkey x Minhardi......	–34	24	37 S	40	B	32	7	73	14.0
Minhardi x Minturki.......	II–19–5	25	17 SR	32	B	32	7	77	14.0
Minhardi x Minturki....	–7	24	17 SR	38	B	32	3	77	16.8
Minard x Minhardi......	II–20–1	24	25 SR	43	A	28	10	68	10.1
Minard x Minhardi.......	–3	24	22 SR	47	A	29	9	70	11.2
Minard x Minhardi........	–4	26	47 S	41	B	32	8	75	12.9
Minard x Minhardi.........	–6	26	12 SR	40	A	33	5	70	17.9
Minard x Minhardi.........	–11	24	25 SR	47	B	31	3	83	19.8
Minard x Minhardi ...	–12	25	23 SR	48	B	31	6	78	16.2
Minard x Minhardi	–14	25	15 SR	53	A	28	3	70	13.7
Minard x Minhardi.........	–15	25	22 SR	38	B	31	5	77	13.6
Minard x Minhardi........	–20	24	28 SR	37	A	34	2	75	15.2
Minard x Minhardi.........	–32	24	27 S	37	B	29	9	72	9.2
Minard x Minhardi.........	–33	25	27 S	47	B	30	5	60	11.3
Minard x Minhardi.......	–34	26	21 S	43	B	30	15	72	8.2
Minard x Minhardi........	–35	24	30 S	53	B	30	1	75	14.4
Minard x Minhardi........	–36	24	17 SR	33	B	30	5	78	14.1
Minard x Minhardi........	–37	26	25 SR	57	A	31	12	77	10.2
Minard x Minhardi.........	–38	25	35 S	43	A	32	10	72	12.4
Crimean.................	Minn. 845	24	43 S	33	B	32	5	78	17.9
Turkey..................	Minn. 1488	27	37 S	36	B	31	18	60	7.8
Minard..................	Minn. 2199	26	32 S	41	B	32	4	64	14.0
Minturki.................	Minn. 1507	25	18 SR	31	B	32	4	78	16.9

[a] R = resistant, S = susceptible, SR = semi-resistant.

[b] B = bearded, A = awnless.

TABLE 6.—*Simple product moment correlation coefficients, correlation ratios, and Blakeman's test of linearity of regression, rod-row trials of winter wheat at Waseca, 1926.*

Characters correlated	r	η	$\frac{\eta^2-r^2}{\text{P. E. } \eta^2-r^2}$
Date heading and percentage stem rust....	+0.1558	0.4249	1.8
Date heading and percentage leaf rust.....	—0.0259	0.3682	1.6
Date heading and plant height...........	+0.2140	0.3100	0.9
Date heading and winter injury..........	+0.5657	0.6156	1.0
Date heading and percentage plumpness...	—0.4110	0.5865	1.9
Date heading and yield............... ...	—0.4341	0.4511	0.5
Stem rust and leaf rust..........	—0.2404	0.3455	1.0
Stem rust and plant height............ ..	+0.0886	0.3828	1.7
Stem rust and winter injury....	+0.2956	0.6283	2.9
Stem rust and percentage plumpness......	—0.4509	0.4999	0.9
Stem rust and yield.......	—0.3045	0.6166	2.8
Leaf rust and plant height...............	—0.3999	0.5184	1.4
Leaf rust and winter injury.............	—0.1295	0.3746	1.5
Leaf rust and percentage plumpness.......	—0.0782	0.2699	1.0
Leaf rust and yield	—0.0470	0.3125	1.3
Plant height and winter injury..	—0.1015	0.3150	1.3
Plant height and percentage plumpness. ..	+0.3583	0.6165	2.4
Plant height and yield..	+0.4578	0.5308	1.1
Winter injury and percentage plumpness...	—0.3334	0.5964	2.4
Winter injury and yield...	—0.7616	0.8141	1.1
Percentage plumpness and yield	+0.6228	0.7499	1.8

The later heading types were somewhat more severely winter injured than the early types. There is also a slight indication that the later heading types are more severely infected with rust. Date heading, stem rust infection, height of plant, plumpness of grain, and winter injury are of importance in relation to yield.

Simple product moment coefficients of correlation and partial correlation coefficients are given in Table 7. From a study of partial correlations it is apparent that earliness of maturity, as shown by date heading, resistance to winter injury, resistance to stem rust, and height of plant which is a measure of vigor are of importance in relation to yield. Height of plant in relation to yield gave a partial correlation coefficient of +0.6251 ±0.0791, while winter injury in relation to yield gave a partial correlation coefficient of —0.6478 ± 0.0753.

Percentage plumpness of grain, stem rust, and leaf rust infection in relation to yield were studied separately (Table 8). Stem rust and leaf rust infection are two important factors which may affect grain plumpness. In the study of partial correlation coefficients the importance of stem rust infection can not be determined if plumpness of grain is held constant.

TABLE 7.—*Comparison of simple product moment coefficients and partial correlations in winter wheat.*

Product moment correlations		Partial	Correlation
Characters correlated	Correlation coefficient	correlations[a]	coefficient
Date heading and stem rust..	$+0.1558 \pm 0.1266$	$r_{AB.CDEH} =$	-0.0959 ± 0.1286
Date heading and leaf rust...	-0.0259 ± 0.1297	$r_{AC.BDEH} =$	$+0.2272 \pm 0.1231$
Date heading and plant height	$+0.2140 \pm 0.1239$	$r_{AD.BCEH} =$	$+0.4755 \pm 0.1005$
Date heading and winter injury	$+0.5657 \pm 0.0883$	$r_{AE.BCDH} =$	$+0.2598 \pm 0.1210$
Stem rust and leaf rust.... .	-0.2404 ± 0.1223	$r_{BC.ADEH} =$	-0.1503 ± 0.1269
Stem rust and plant height...	$+0.0886 \pm 0.1288$	$r_{BD.ACEH} =$	-0.2005 ± 0.1246
Stem rust and winter injury..	$+0.2956 \pm 0.1185$	$r_{BE.ACDH} =$	0.0000 ± 0.0000
Leaf rust and plant height...	-0.3999 ± 0.1090	$r_{CD.ABEH} =$	-0.3821 ± 0.1109
Leaf rust and winter injury..	-0.1295 ± 0.1276	$r_{CE.ABDH} =$	-0.1459 ± 0.1270
Plant height and winter injury	$-0.1015 + 0.1285$	$r_{DE.ABCH} =$	$+0.1865 \pm 0.1253$
Yield and date heading.....	-0.4341 ± 0.1053	$r_{HA.BCDE} =$	-0.2926 ± 0.1187
Yield and stem rust..... .	-0.3045 ± 0.1178	$r_{HB.ACDE} =$	-0.2672 ± 0.1209
Yield and leaf rust.	-0.0470 ± 0.1295	$r_{HC.ABDE} =$	$+0.0500 \pm 0.1295$
Yield and plant height......	$+0.4578 \pm 0.1026$	$r_{HD.ABCE} =$	$+0.6251 \pm 0.0791$
Yield and winter injury.....	-0.7616 ± 0.0545	$r_{HE.ABCD} =$	-0.6478 ± 0.0753

[a] A = date heading, B = percentage stem rust, C = percentage leaf rust, D = height of plant in inches, E = percentage winter injury, H = average yield in bushels per acre.

Apparently stem rust is an important cause of shriveling of grain in these winter wheat studies, although other factors also influence plumpness of grain. Plumpness of grain is intimately related to yielding ability and the partial correlation coefficient for plumpness and yield, holding constant stem and leaf rust infection, was $+0.5608 \pm 0.0890$.

The multiple correlation coefficient was calculated to determine the extent to which yield or H was a function of the variables date of heading, percentage infection of stem rust, percentage infection of leaf rust, height of plant in inches, percentage winter injury, and percentage plumpness of grain. A calculated value of $R_{H.ABCDEK} =$

TABLE 8.—*Comparison of simple product moment coefficients and partial correlations in winter wheat.*

Product moment correlations		Partial	Correlation
Characters correlated	Correlation coefficient	correlations[a]	coefficient
Stem rust and leaf rust......	-0.2404 ± 0.1223	$r_{BC.HK} =$	-0.3098 ± 0.1173
Stem rust and plumpness....	-0.4509 ± 0.1034	$r_{BK.HC} =$	-0.3821 ± 0.1108
Leaf rust and plumpness.....	-0.0782 ± 0.1290	$r_{CK.HB} =$	-0.1735 ± 0.1259
Yield and stem rust.........	-0.3045 ± 0.1178	$r_{HB.CK} =$	-0.0346 ± 0.1296
Yield and leaf rust	-0.0470 ± 0.1295	$r_{HC.BK} =$	-0.0100 ± 0.1298
Yield and plumpness	$+0.6228 \pm 0.0795$	$r_{HK.BC} =$	$+0.5608 \pm 0.0890$

[a] B = percentage stem rust infection, C = percentage leaf rust infection, K = percentage plumpness of grain, H = yield in bushels per acre.

0.8961 was obtained. On this basis 55.61% of the total variation in yielding ability has been accounted for. A multiple correlation coefficient of $R_{K.ABCDE} = 0.7552$ was obtained. On this basis 34.45% of the total variation in plumpness of grain was accounted for by the factors considered. This is of interest as plumpness of grain is of so much importance in relation to yield.

It is apparent that a considerable amount of the total variability in yield in the rod-row trials of spring and winter wheat has not been explained by the characters considered. There are intangible factors of inheritance that are not so easily measured. The most striking botanical difference of the spring and winter wheat strains is that certain of these are awnless and others are bearded. It has been pointed out previously that the awn of barley and wheat is an important physiologic organ. Table 9 gives a comparison of percentage plumpness of grain of bearded and awnless lines of the spring and the winter strains used in these studies.

TABLE 9.—*Relation in spring and winter wheat of percentage plumpness of grain and awnless or bearded character.*

Type of wheat	Percentage plumpness classes											
	54	57	60	63	66	69	72	75	78	81	84	87
Winter, bearded			2	1		2	4	2	7		1	
Winter, awnless		1				4	1	1	1			
Spring, bearded				1	1	4	5	5	12	6	4	2
Spring, awnless	1	1			1	1	4		2			

It is apparent from a consideration of these data that the bearded strains on the average excelled in plumpness of grain. As plumpness of grain and yield are strongly correlated, it seems that bearded wheats yield better on the average than awnless wheats when grown under southern Minnesota conditions.

DISCUSSION

A study of the correlation of characters in relation to yielding ability furnishes the plant breeder with a method of determination of the relative importance of certain characters in their influence on yielding ability. This makes possible a logical plan of attack. In attempting the improvement of small grains by cross-breeding the variety used as one parent, because of some special characteristic, such as resistance to stem rust, may transmit an undesirable character, such as susceptibility to leaf rust or black chaff, which previously had received little attention because the varieties grown were resistant to these diseases. Such results were obtained from crosses with Kota. It appears that there may be a linkage between the genetic factors responsible for susceptibility to black chaff of the Kota parent and the factors responsible for resistance to stem rust.

Reaction to leaf rust was important in relation to yielding ability in the spring wheat studies when other factors were held constant. It is apparent that a new variety of spring wheat, which is produced for the purpose of controlling stem rust, should also be resistant to leaf rust. The varieties Ceres and Marquillo which have been recommended recently for distribution in Minnesota are resistant to both stem and leaf rust. Ceres, however, is susceptible to loose smut and black chaff, while Marquillo is somewhat more susceptible to root rot than some other varieties of *Triticum vulgare.* These characters will receive more attention in further studies.

All of the winter wheats grown in these studies apparently are susceptible to leaf rust. The effect of leaf rust on yield could not be determined, therefore, in the winter wheat series. It appears of importance to obtain winter wheats which are as desirable as Minturki, or more so, and which also are resistant to leaf rust. This fact is of value in relation to the present winter wheat breeding experiments which are under way. Crosses of Marquis with Minturki and Minhardi are being studied. Lines are available in the F_5 generation which are as winter hardy as the winter wheat parents. Selection for leaf rust resistance will be made as certain of the hybrids very probably have inherited the resistance to leaf rust of the Marquis parent.

SUMMARY

1. The rod-row trials of spring and of winter wheats made at Waseca in 1926 furnished an opportunity to study the relative importance of various agronomic and botanical differences, as well as reaction to certain diseases, in their influence on yielding ability.

2. Each of the lines studied was grown in three systematically distributed plats of three rows each. The central row of each plat was harvested for the yield trials. Data for all characters were obtained from each plat and the results were averaged.

3. A study of the correlation surfaces, together with Blakeman's test of linearity, indicated sensible linearity of regression in nearly all cases. The apparent deviations from linearity were due to single variates in frequency classes in which there were only a few individuals. Consequently, the correlation coefficient was believed to be the best measure of relationship in all of the studies, except in a study of the disease known as black chaff where the data were taken in categories.

4. All of the Kota hybrids proved as susceptible to black chaff as the Kota parent which indicates the probability that the genetic factors for reaction to the organism which caused this disease may be linked with genetic factors for resistance to stem rust.

5. Stem rust and leaf rust, date heading, height of plant, and percentage plumpness of grain were of importance in relation to yielding ability in spring wheat. The calculated multiple correlation coefficient of yield in relation to these five variables was 0.6592. On this basis 24.8% of the total variability in yield was accounted for.

6. These same factors and winter injury were studied in winter wheat. A multiple correlation coefficient for yield in relation to these six factors was calculated. A value of R = 0.8961 was obtained. On this basis 55.61% of the variability in yield of the winter wheat varieties was accounted for.

7. Percentage plumpness of grain and yield were correlated to the extent of +0.5101 in spring wheat and +0.6228 in winter wheat. A simple note regarding grain plumpness is of much importance apparently in an estimate of the probable value of a new selection or hybrid variety. Selection on the basis of grain plumpness appears well worth while during the segregating generations of hybrids when accurate data are not available.

8. The bearded selections produced plumper grain on the average than the awnless ones.

INFLUENCE OF FERTILIZER TREATMENTS ON MATURITY AND YIELD OF COTTON[1]

G. W. Musgrave and Dana G. Coe[2]

It is the purpose of the present paper to report the results obtained from studies of various methods of applying fertilizers as they affect the maturity and yield of cotton. In these studies, the methods used permitted comparisons of the concentration of fertilizer salts about the seed by varying (a) the rate of application, (b) the fertilizer ratio, (c) the time interval elapsing between application of fertilizer and planting of seed, and (d) the location of the fertilizer salts with reference to seed.

In a previous paper the authors (2)[3] describe the effects of these fertilizer treatments on stand of cotton. It was shown that the increased concentration of fertilizer salts, including the common nitrogen sources, potash, and to a lesser extent acid phosphate, reduced the germination of cotton. This inhibition of germination was not marked in (a) the lower rates of application, (b) the lower fertilizer ratios, (c) longer time intervals between fertilizer application and planting of seed, or (d) the fertilizer locations at greater distances from the seed.

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[1] Contribution from the American Cyanamid Co., 535 Fifth Ave., New York, N. Y. Received for publication July 23, 1927.

[2] Agronomist and Regional Agriculturist, respectively.

[3] Reference by number is to "Literature Cited," p. 923.

The plat arrangement, as described in the previous paper, included a minimum of six replications of each treatment, excepting only in the Oklahoma work, and permitted in several instances comparisons of series of 36 or more fortieth-acre plats.

Although the work herein reported is that of a single year, its scope is such that significant results have been secured. Moreover, the weather conditions under which the work was conducted were unusually rigorous by reason of the low rainfall which prevailed during the germinating period. The effects of the treatments upon stand are, therefore, doubtless more marked than would normally be the case. It is believed however, that those methods and treatments which produced good germination under such dry conditions would also produce good stands under more favorable or normal ones.

MATURITY DIFFERENCES

One of the striking, and at first surprising, results noticed is the apparent relationship between the maturity of the plants and the fertilizer injury. That is to say, fertilizer treatments which did not produce appreciable injury to the germination were also associated with marked earliness of maturity. No definite cause for this relationship is advanced at the present time other than the possibility of seedling root injury and subsequent retardation of the powers of assimilation of the plants as well as a partial stunting of the plants by those applications made in too close proximity to the seed.

In Table 1 it is seen that the percentage of cotton obtained at the first picking is appreciably greater from the check plats than from those plats receiving phosphate plus potash. The phosphate plus potash plats are likewise somewhat earlier in maturity than the plats receiving nitrogen, phosphate, and potash.

TABLE 1.—*Influence of various fertilizers on maturity of cotton, North Carolina field.*[a]

Fertilizer treatment	Number of 1/40-acre plats averaged	Percentage total crop at first picking
500 pounds 10–4–4 per acre.....	36	51.28
500 pounds 10–0–4 per acre......	6	54.24
Check (no fertilizer)............	6	63.26

[a] All data from the North Carolina field were obtained under the immediate supervision of W. H. Rankin, Regional Agriculturist of the American Cyanamid Co.

It is generally recognized that excessive quantities of nitrogen tend to delay the maturity of a plant. Whether or not these effects are entirely nutritional and physiological or whether they may in part be associated with injury to the plant is not known. The theory of a possible dual effect is a plausible one, since it is clear that the larger concentrations of potash, and to a lesser extent of phosphate, have similarly retarded maturity. In the absence of any direct evidence as to the cause of the phenomenon, these effects may be attributed to root injury and pruning and consequent delayed feeding by the plant.

In Table 2 a general retardation of the maturity of the cotton is found as the nitrogen ratio increases. All of the common mineral sources of nitrogen were used singly and in separate series and no significant differences were apparent among them. The figures vary somewhat, but the trend is clearly observable.

TABLE 2.—*Effect of increasing quantities of nitrogen on maturity of cotton, North Carolina field.*[a]

Pounds of nitrogen applied per acre[b]	Percentage total crop at first picking
20	40.70
30	33.24
40	36.53
50	31.95

[a] Number of 1/40-acre plats in each series was 90.

[b] 50 pounds P_2O_5 and 20 pounds K_2O applied to all series.

The effect of these increasing nitrogen applications, hence the concentration of soluble salts, has been to reduce the stand of the plants, as previously reported. These relationships are observable throughout all of the data.

All of the several nitrogen sources when applied at the time of planting produced lower germination than when applied one, two, or three weeks before planting. The relative maturity of the plants on the plats where the nitrogen applications were made at the time of planting was also later than where the nitrogen was applied prior to planting, as shown in Table 3.

TABLE 3.—*Time of application and maturity of cotton in North Carolina field.*[a]

Nitrogen applied	Percentage total crop at first picking
3 weeks before planting	38.76
2 weeks before planting	34.25
1 week before planting	40.67
At planting	33.83

[a] Number of 1/40-acre plats in each series was 72.

The direction of the trend is not fully apparent. The best stands were obtained from the applications made one week before planting, with the two weeks, three weeks, and at planting applications following in order. As measured both by germination and maturity, however, the treatments at planting were clearly inferior to those made at an earlier date. Since the weather conditions prevailing at one or another of the dates of application may influence considerably the results secured from that treatment, no definite conclusions are drawn from these time series. Their consistent relationship to the other portions of the work, however, emphasizes their being an integral part of the whole.

No large amount of work was done on phosphate and potash singly, but comparisons between applications of phosphate and potash at planting and nitrogen one week in advance of planting with applications in which all of the materials were made in advance of planting showed a better average germination from the latter method of application. The differences in maturity were slight, but the trend in favor of the earlier applications of phosphate plus potash was nevertheless definite.

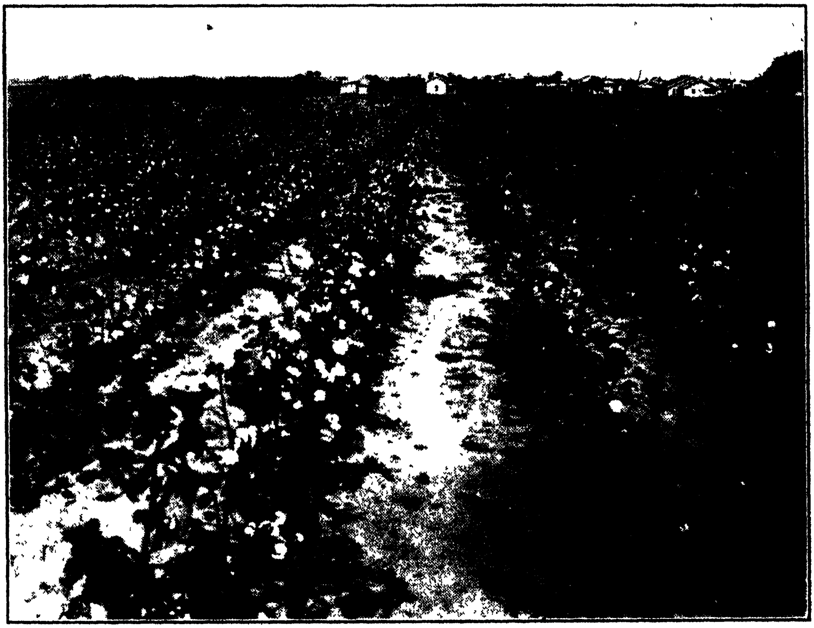

FIG. 1.—Differences in maturity due to method of fertilizer application. On left 12-4-4 fertilizer application at "Sides." On right "Below and Wide."

The location of the fertilizer with relation to the seed has a striking influence on maturity, as is shown in Fig. 1. Those fertilizer locations which have permitted the best germination are the locations which also have produced the earliest maturity in the crop. These differences are more striking for the complete fertilizers than they are for acid phosphate alone.

TABLE 4.—*Effect of time of application of phosphate and potash on maturity of cotton, North Carolina field.*[a]

Treatment	Percentage total crop at first picking
P and K at planting, N one week in advance	55.75
All materials one week in advance of planting	56.54

[a] Number of 1/40-acre plats in each series was 48.

In Table 5 is given a summary of the form counts made September 21 and 22 in which the number of bolls is calculated as a percentage of the total number of forms (blooms, squares, and bolls). The percentage of bolls calculated in this manner appears to give a very satisfactory index of maturity and permits finer comparisons than does a simple bloom count or a similar index.

TABLE 5.—*Effect of method of application on maturity (percentage of bolls), Oklahoma field.*

Location of fertilizer	Fertilizer formula			Average
	12-4-4[a]	12-0-4[b]	12-0-0[b]	
Direct contact				
Bolls	815	997	1,577	1,003.80
Total forms[c]	2,503	3,021	2,841	2,674.00
Percentage bolls	32.57	33.00	55.51	37.54
Below 1 inch narrow				
Bolls	1,172	794	1,139	1,090.00
Total forms	3,377	2,784	2,772	3,137.20
Percentage bolls	34.72	28.52	41.09	34.74
Below 2 inch narrow				
Bolls	1,361	1,409	1,709	1,440.20
Total forms	3,505	3,585	2,732	3,366.20
Percentage bolls	38.84	39.30	62.55	42.78
Below 1 inch wide				
Bolls	1,574	1,363	1,604	1,537.80
Total forms	3,500	3,068	2,909	3,295.60
Percentage bolls	44.97	44.43	55.14	46.66
Above				
Bolls	1,892	1,622	1,691	1,798.00
Total forms	3,417	3,127	2,683	3,212.20
Percentage bolls	55.38	51.87	63.03	55.97
One side				
Bolls	1,921	1,650	1,499	1,742.20
Total forms	3,251	2,795	2,315	2,972.80
Percentage bolls	57.02	59.03	64.75	58.60
Both sides				
Bolls	1,912	1,868	1,830	1,887.00
Total forms	3,396	3,075	2,588	3,170.00
Percentage bolls	56.32	60.75	70.71	59.53
Total bolls		9,703	11,049	
Total forms		21,455	18,840	
Average percentage of bolls	46.11	45.22	58.65	

[a] Averages of six 1/40-acre plats for each method of application.

[b] Averages of two 1/40-acre plats for each method of application.

[c] Averages of 150 feet of row per plat.

The average percentage of bolls from each of the seven methods of application shows a fairly regular increase as the comparison progresses from the direct contact applications to the applications at both sides of the seed. The stand counts, previously reported, showed a like increase in germination as the comparison progressed in the same direction. It appears that the locations of the fertilizer materials in direct contact and below the seed have produced sufficient injury to the seedlings to retard their normal development.

These maturity differences, however, are far less striking in the applications of phosphate alone than they are in the application of phosphate plus potash or in the case of nitrogen, phosphate, and potash. With phosphate, the percentage of bolls ranges from 41 to 70; with phosphate plus potash from 28 to 60; and with nitrogen, phosphate, and potash from 32 to 57. The phosphate applications ordinarily produced little injury to the germination. Phosphate plus potash, however, produced greater inhibition of germination, as did also the complete fertilizer.

A comparison of all the phosphate applications with the phosphate plus potash applications shows 58.65% bolls for the former and 45.22% for the latter. The difference in maturity between the phosphate plus potash applications in the seven methods of application and those of the complete fertilizer is less striking, showing 45.22% bolls for the former and 46.11% for the latter.

The addition of nitrogen, therefore, has not appreciably delayed the maturity beyond that of the phosphate plus potash, where in fact the retardation may be largely attributed to the potash. The slight differences, however, in percentage of bolls between the two fertilizer treatments as a whole or by the separate methods of application are not considered to be significant.

The increased earliness observable in the applications in a wide band beneath the seed, in the applications above the seed, and in the applications at one side of the seed or at both sides of the seed is striking.

DISCUSSION OF RESULTS ON MATURITY

The pronounced parallelism in germination and maturity resulting from fertilizer treatments is a matter of considerable interest and its practical importance needs no further emphasis. Neither are the results out of harmony with other available records.

Millar and Mitchell (1) have shown that fertilizer applications in contact with the seed are quite toxic, those above the seed less so, and applications broadcast practically non-injurious. A complete commercial fertilizer with a 3–12–4 analysis proved more toxic than

16% acid phosphate, probably because of the high solubility of the ammonium and potassium salts present.

Smith and Harper (3) showed that where a 2-12-2 fertilizer application at the rates of 100 and 200 pounds per acre is made in the hill thoroughly mixed with a layer of soil 3 inches wide, 12 inches long, and 1 inch deep, the assimilation of nitrogen by the fertilized plants was proportionately greater than would be indicated by the amount of fertilizer applied. This is said to suggest that the root systems of the fertilized plants were considerably larger than those of the unfertilized plants, since much larger amounts of nitrogen were obtained from the surrounding soil by those fertilized than those unfertilized.

The method of application for this fertilizer dosage appears to be a good one but, of course, difficult to secure by machinery. Under such conditions, an earlier and more thorough assimilation of nutrients seems entirely logical.

Warner (4) showed a higher percentage of cotton obtained at the first picking of the crop on his check plats than on many of the fertilized plats. The percentage which is obtained at the first picking is usually greatest with the normal applications of nitrogen or potash and then falls off with larger applications. The exception to this is in the case of the phosphate applications which increase the percentage of cotton at the first picking, all of which results are in harmony with those reported herein.

As regards nitrogen specifically, Warner showed that it increased the rate of fruiting after the second week as well as prolonged the fruiting. The total form counts in these tests show the same fact very forcibly in all of the good methods of application.

Williams (5) found as an average of six years' comparison that increasing the potash ratio from a 10-4-2 to a 10-4-6 reduced the amount of cotton open at the first picking from 65% to 55%. In a rate of application comparison he also shows a retardation of maturity in the highest rates applied in two out of three cases.

The effect of phosphate in hastening maturity has been long recognized. Williams shows specifically on cotton that the percentage of total crop open at the first picking increased from 51 to 70 when the phosphate content of the fertilizer was increased from 7% to 21%.

The data reported herein show similar results when applications were not concentrated about the seed, but they show that even in the case of acid phosphate the maturity of the cotton plant was delayed in the cases where the applications were adjacent to or concentrated about the seed. Still more marked are the effects of the very soluble and active salts of nitrogen and potassium. While it is recognized that nitrogen normally retards maturity and that potassium may have a similar physiological effect, it seems plausible to assume that in some cases at least the effects are augmented by the manner of applying these materials to the soil.

YIELDS

The yield records reported herein were obtained by making three pickings on the North Carolina plats, as is customary in that section. On the Oklahoma field the cottom was harvested as snapped cotton and the weights are reported as such.

The response from phosphate plus potash on the North Carolina field averages 36 pounds of seed cotton per acre above that of the check plat. The response from nitrogen, phosphate, and potash over the phosphate plus potash plats amounts to 180 pounds of seed cotton per acre. These yields are given in Table 6.

TABLE 6.—*Yields of seed cotton, North Carolina field.*

Fertilizer treatment	Number of 1/40-acre plats averaged	Pounds per acre
500 pounds 10-4-4 per acre	36	920.15±25.21
500 pounds 10-0-4 per acre	6	740.10±79.23
Check (no fertilizer)	6	704.01±28.12

The rather large probable error obtained from the six plats of the 10-0-4 treatment is not unexpected in view of the fewer number of replications than in the 10-4-4 treatments. It seems clear, however, that there is a very significant increase in the yield of the complete fertilizer above the check plats. The response from nitrogen, phosphate, and potash also appears to be considerably greater than that from the phosphate plus potash.

In the comparison of the varying nitrogen quantities the effect has been to increase the yields as the quantity increases from 20 pounds to 30 pounds per acre, after which a slight decrease occurs at 40 pounds and a considerable decrease at 50 pounds per acre. The differences in yield from the 20-, 30-, and 40-pound treatments when measured in terms of their probable errors are not significant, however. The yields of the 20- and 30-pound treatments are significantly better than those secured from the 50-pound application.

TABLE 7.—*Effect of increasing quantities of nitrogen on yield, North Carolina field.*[a]

Pounds of nitrogen applied per acre[b]	Pounds per acre
20	970.35±22.05
30	988.60±20.60
40	935.50±21.31
50	895.67±21.14

[a] Number of 1/40-acre plats in each series was 90.

[b] 50 pounds P_2O_5 and 20 pounds K_2O applied to all series.

The effect of the time of applying the fertilizer very clearly was to increase the crop as the interval before planting was increased. In view of both the lower germination and the later maturity resulting from the applications at planting, it is natural to expect a lower yield also on these same plats. However, the best stand and the earliest maturity was obtained from the treatments made one week before planting. Nevertheless, the final yield from these treatments was not as great as from the applications made two weeks before planting or from those made three weeks before planting, as shown in Table 8.

TABLE 8.—*Time of application and total yield of cotton, North Carolina field.*[a]

Nitrogen applied	Pounds per acre
3 weeks before planting	1,039.63±24.03
2 weeks before planting	1,017.70±26.16
1 week before planting	923.88±23.72
At planting	831.37±18.95

[a] Number of 1/40-acre plats in each series was 72.

Measuring these differences in terms of their probable error, the applications made three, two, and one week before planting are significantly better than those made at planting. Also, the applications made three weeks and two weeks before planting are significantly better than those made at one week before planting. The applications made three weeks before planting are not significantly better than those made two weeks before planting.

The effect of advancing the time of application of the phosphate and potash by one week, where the nitrogen application is made one week in advance in both cases, has been to increase the yield somewhat, although the increase is within the limits of error of the experiment. These results are shown in Table 9.

TABLE 9.—*Effect of time of application of phosphate and potash on maturity, North Carolina field.*[a]

Treatment	Pounds per acre
P and K at planting, N one week in advance	867.46±26.95
All materials one week in advance of planting	894.43±32.15

[a] Number of 1/40-acre plats in each series was 48.

The effect of the method of applying the fertilizer materials on yield as obtained in the Oklahoma experiment has been striking. The yields have increased fairly regularly as the method of application successively varies from direct contact of the fertilizer or a concentrated application below the seed to a wider dispersal. The trend in this direction is quite marked in the phosphate plus potash mixtures (12-0-4) and the complete fertilizer (12-4-4). The trend is not as clearly marked, however, where acid phosphate only is used. The yields are given in Table 10.

TABLE 10.—*Effect of method of application on yield, Oklahoma field, pounds of snapped cotton per acre.*

Location of fertilizer	Fertilizer formula			Average
	12-4-4[a]	12-0-4[b]	12-0-0[b]	
Direct contact	240	580	1,020	464.00
Below 1 inch narrow	453	540	580	496.00
Below 2 inch narrow	673	760	960	748.00
Below 1 inch wide	513	660	920	624.00
Above seed	933	980	1,040	964.00
One side of seed	1,040	980	1,060	1,032.00
Both sides of seed	1,020	940	940	988.00
Average				759.43
Mean of seven checks				525.6±32.48

[a] Averages of six 1/40-acre plats for each method of application.

[b] Averages of two 1/40-acre plats for each method of application.

The results in several instances are somewhat erratic, but the trend towards an average increase in yield as the method of application reduces concentration of salts about the seed is quite definitely marked. The average yields from the various locations of fertilizer materials very closely parallel the germination and maturity data. Plats receiving side-of-seed treatment yielded 90% more than did the check plats, showing a very satisfactory response from these treatments. The soil is plainly a phosphate deficient one and the yield response to additions of nitrogen and potash appears only in the good methods of fertilizer application. In the poor methods, for example the direct contact applications, the yields decrease as the fertilizer ratio or the concentration of soluble salts increases.

DISCUSSION OF YIELDS

It is, of course, recognized that the yield of a crop per unit area of land is the product of a considerable number of factors. The stand and spacing of the plants, the relative maturity of the plant, and the yield per plant are but several of the more important ones. With relatively wide spacing of plants the normal yield per plant is greater, all other conditions being equal. In the present experiment, the yield per plant is further modified by variations in the fertilizer treatments. It is not surprising, therefore, that the average yields per plat are not in all cases in the same order of rank as the ranking by germination or by relative maturity.

On the North Carolina field the increase in yield resulting from the complete fertilizer treatments as compared with the check plats shows the response from nitrogen, phosphate, and potash to be marked, even though a certain reduction of germination and a retardation of maturity resulted from these treatments. Increasing quantities of nitrogen also increased the yield up to the usually recommended ratio (6%). The lower yield from the 10% nitrogen treatment may be attributed in part to the excessive vegetative growth, as well as to the reduced stand and the delayed maturity resulting from these treatments. These effects were not associated with any particular nitrogen source either, since there were no significant differences in the results in this respect from any of the sources. The applications before planting also were superior in yield response, as well as in germination and early development, to those made at planting. When applied at planting, the phosphate plus potash combination (10-0-4) gave results similar to though less marked than those of the complete fertilizer (10-4-4). The improvement resulting from modifications of the method of application or location of the fertilizer with reference to the seed was marked with all materials except acid phosphate alone, which has been shown to be less injurious to seedlings than potassium and nitrogen salts. The superior stands, maturity, and yield obtained from the locations at the side of the seed appear to confirm the belief that a method of application providing such a position of salts is fundamentally sound.

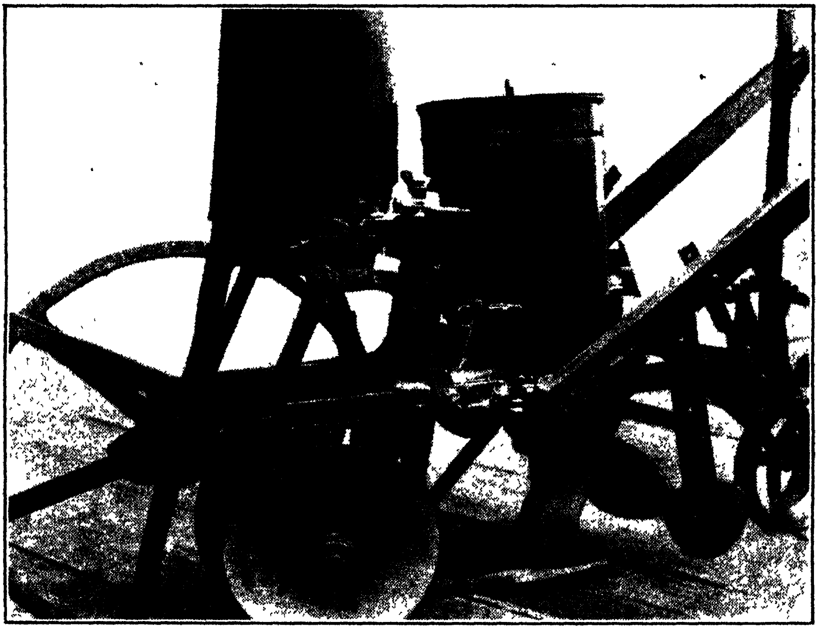

FIG. 2.—A combination planter and fertilizer distributor equipped to give applications of fertilizer on both sides of the seed.

PRACTICAL APPLICATIONS

Although the placing of fertilizers in an ideal location may not be feasible with certain types of equipment now in use and under certain practices now in vogue, the ideal may be approximated under many conditions. In this way a substantial improvement in the use of fertilizer materials in many sections may be effected. Fig. 2 shows a combination planter and distributor which has been successfully used to make fertilizer applications at the side of the seed row.

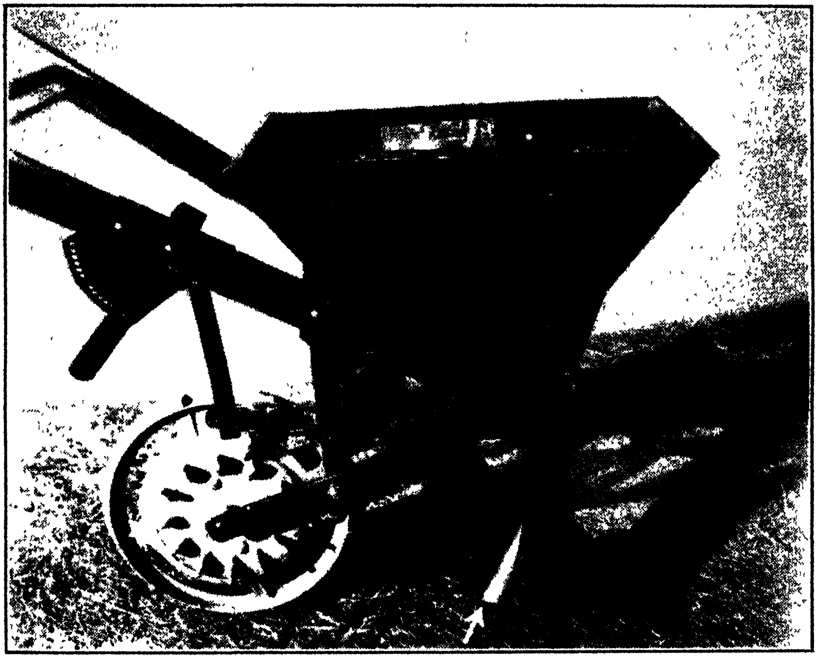

FIG. 3.—Fertilizer distributor to which a deflector "A" has been attached beneath the fertilizer spout to give wide dispersion of fertilizer materials.

In Fig. 3 is shown a sheet-iron deflector attached beneath the fertilizer outlet pipe. This deflector has been successfully used to obtain a width of distribution from 4 to 10 inches or a split stream when the angle is less steep. The attachment of a buzzard wing sweep to the distributor to follow behind the fertilizer stream serves to distribute the fertilizer and incorporate it with the soil. Many other adjustments of present equipment are possible which will have as their object good dispersion of the fertilizer and incorporation with the soil whenever the usual soluble salts are applied.

SUMMARY

The results of certain fertilizer treatments shown in a previous paper in their effects upon germination and stand of cotton are herein shown in their effects upon maturity and yield.

Earlier maturity occurred on the check plats than on those receiving an application of 500 pounds of a 10–0–4 per acre, which in turn were earlier in developing than the plats receiving a like quantity of 10–4–4 fertilizer.

Increasing the nitrogen ratio from 4 to 6, 8, and 10% showed a trend towards later maturity with the higher ratios.

Applications of nitrogen before planting produced earlier maturity than those at planting for the methods of distribution employed.

Applications of phosphate and potash before planting produced slightly earlier maturity than those at planting.

The maturity was delayed by applications in contact with the seed or immediately beneath the seed and was earlier on the average as the treatments were placed deeper, wider, above, or at the side of the seed.

The yields from a complete fertilizer were significantly greater than from check plats receiving no fertilizer.

The yields from increasing quantities of nitrogen increased from applications of 20 pounds and 30 pounds of nitrogen, then slightly decreased at 40 pounds, and were significantly less at 50 pounds per acre.

Applications of the several nitrogen salts before planting produced larger yields than those at planting.

Applications of the phosphate-potash combination before planting were apparently somewhat better in yield than those at planting.

In the comparison of locations of fertilizer materials the yields from applications in contact with the seed were the lowest but increased on the average in the 1 inch below, 2 inches below, below wide, above, and side-of-seed positions, to the highest yields in the last location.

The yield increase resulting from proper fertilizer locations was more marked in the 12–4–4 and 12–0–4 materials than in the acid phosphate treatments.

The side-of-seed position appears to be an ideal location which may be approximated with slight modifications of many types of equipment now in use, thereby obtaining more effective results from the use of any fertilizer material.

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RESIDUAL EFFECTS OF DIFFERENT IRRIGATION TREATMENTS ON THE CROPS GROWN THE SUCCEEDING YEAR[1]

D. W. ROBERTSON AND ALVIN KEZER[2]

In an earlier paper (3)[3] the writers presented the results of an experiment to determine the effect of applying irrigation water at different stages in the growth of the wheat plant. During the course of these investigations it was soon noticed that crops grown the following year behaved differently after each of the several treatments. Accordingly, a definite set of experiments was planned to measure the effect of the several treatments upon succeeding crops. For lack of a better name, these have been called "residual effects." Four years' "residual" results are reported in this paper.

EXPERIMENTAL RESULTS

The experiment on residual effect of irrigation water on the succeeding crop was started in 1922. Plats which had been in the critical period experiment in 1921 (3) were sown to Marquis wheat in 1922. No irrigation water was applied during the season and the only moisture added was that which fell as rain or snow. Square yards were marked off in the center of the plats occupied by each treatment of the critical period experiment of the previous year. Fig. 1 shows the stakes marking the center of the plats of the residual experiment in 1925. At harvest time an iron frame 1 yard square (1) was placed over the stake and 1 square yard of the crop was harvested from each

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[3] Reference by number is to "Literature Cited," p. 943.

plat. This was carefully wrapped in cloth and stored until thrashing. At thrashing time the entire sheaf was weighed and the weight of the sheaf minus the cleaned grain weight was taken as the straw yield.

In cutting the plats grass shears were used. The plats were clipped at as nearly a uniform height from the ground as possible. The plats were replicated four times (five plats) as in the previous treatment. Similar methods (3) were used in 1923, 1924, and 1925.

Table 1 gives the rainfall which fell on the residual plats from the time the canvas covers were removed from the critical period experiment in the previous year to the date the crop was harvested.

Table 1.—*Rainfall falling on residual plats from the time the canvas covers were removed to the time of harvest in the following year.*

	1921 to 1922	1922 to 1923	1923 to 1924	1924 to 1925
October	0.53	0.50	3.55	——
November	0.24	1.37	0.10	0.09
December	0.89	0.26	0.25	0.74
January	0.35	0.19	0.51	0.27
February	0.53	1.39	0.54	0.08
March	0.32	2.74	1.83	0.39
April	2.95	2.18	0.93	0.05
May	0.46	3.60	3.90	0.97
June	1.03	5.72	0.22	1.99
July	0.83	5.26	0.16	1.06
August		0.05	0.05	——
Total	8.13	23.26	12.04	5.64

Table 1 shows that the rainfall varied from 5.64 inches in 1924 to 1925 to 23.26 inches in 1922 to 1923. In years when the rainfall was low, 1921 to 1922 and 1924 to 1925, the effect of the previous irrigations was more marked. Fig. 1 shows the effect of the 1924 treatment on the 1925 crop.

Table 2 gives the location of the different plats and their treatment in 1924.

DISCUSSION OF YIELD

The yields of the different plats, given in pounds per acre, are shown in Tables 3 and 5. The chances that the differences are significant are given as odds and were obtained by Student's method (4, 5). Table 4 gives the odds for the grain yield, straw yield, combined grain yield, combined straw yield, and combined grain and straw yield.

GRAIN YIELD OF RESIDUAL PLATS

In discussing the yields from the residual plats the different treatments refer to the periods of irrigation of the previous year. The residual yields are obtained from crops grown in the following year on these plats.

Table 3 shows that the plats irrigated the previous year at "heading," "blossoming," and "filling" gave the highest residual yields. The residual plats following those irrigated at "heading" the previous year outyielded the residual plats irrigated at "jointing" by 267 pounds. The residual plats irrigated the previous year at "heading" outyielded the residual plats irrigated at "tillering" by 351.6 pounds and the residual plats at "germination" by 393.1 pounds. The residual plats irrigated at "blossoming" the previous year outyielded the residual plats irrigated at "jointing" by 192.2 pounds.

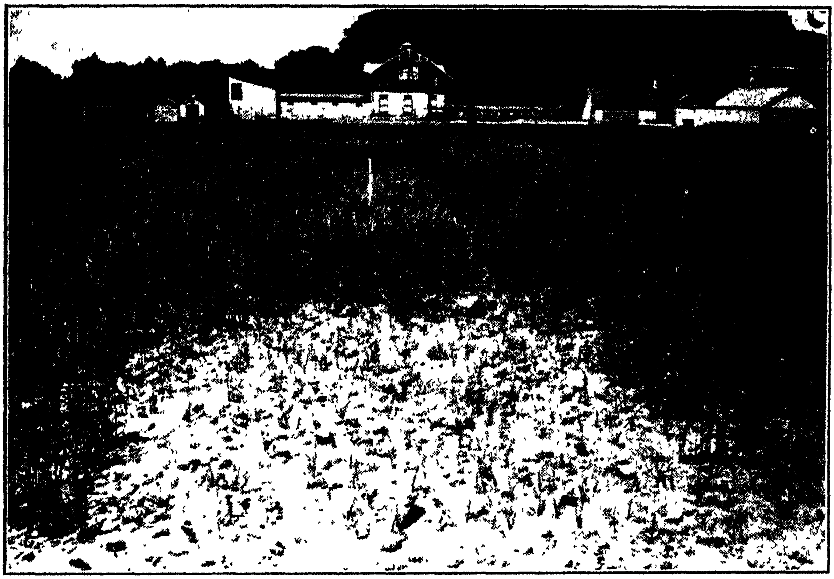

FIG. 1.—Residual effects on the 1925 crop of Marquis wheat sown on Series G following the 1924 critical period experiment. Plat X in the foreground.

The residual plats irrigated at "jointing" the previous year outyielded the residual plats irrigated at "filling" by 446.0 pounds. The difference between the residual plats irrigated at "heading" the previous year and the residual plats receiving a "distributed" irrigation was 268.5 pounds in favor of the plats irrigated at "heading." The residual plats irrigated the previous year at "heading" outyielded the residual plats receiving "no irrigation" by 283.9 pounds. The residual plats irrigated the previous year at "heading" outyielded the residual "keep growing" plats (1 inch at "germination") by 249.1 pounds. The difference between the residual plats irrigated the previous year at "blossoming" and the residual

TABLE 2.—*Plan showing treatment and location of critical period plats in 1924.*

Plat	Series A	Series B	Series C	Series D	Series E .	Series F	Series G
I	Keep growing	No irrigation	Keep growing	No irrigation	Keep growing	No irrigation	Keep growing
II	Heading	Germination	Blossoming	Filling	Jointing	2 irrigations	Heading
III	Tillering	Filling	Distributed	Distributed	Heading	Germination	Blossoming
IV	Blossoming	Jointing	Heading	Germination	Filling	Tillering	Distributed
V	Filling	Blossoming	2 irrigations	Tillering	Distributed	Jointing	Germination
VI	Distributed	Tillering	Jointing	Heading	Blossoming	Filling	2 irrigations
VII	2 irrigations	2 irrigations	Germination	Blossoming	Tillering	Distributed	Jointing
VIII	Germination	Heading	Filling	Jointing	2 irrigations	Blossoming	Tillering
IX	Jointing	Distributed	Tillering	2 irrigations	Germination	Heading	Filling
X	No irrigation	Keep growing	No irrigation	Keep growing	No irrigation	Keep growing	No irrigation

TABLE 3.—*Yield of grain in pounds per acre on the residual plats for a four-year period from 1922–1925, inclusive.*

Year	Germination	Tillering	Jointing	Heading	Blossoming	Filling	Distributed	No irrigation	Keep growing
1922	544.2	853.6	971.0	1,131.0	1,120.4	1,333.7	896.3	939.0	1,035.0
	917.6	1,152.4	1,163.0	1,451.1	1,184.4	1,493.8	1,056.3	832.3	1,077.7
	1,131.0	960.3	1,088.3	1,472.5	1,013.6	1,344.4	939.0	1,024.3	1,003.0
	971.0	949.6	1,333.7	1,472.5	1,067.0	1,269.7	939.0	1,045.7	885.6
	1,013.6	1,013.6	1,003.0	1,557.8	1,376.4	1,248.4	1,109.7	981.6	1,003.0
Average	915.5	985.9	1,111.8	1,417.0	1,152.4	1,338.0	988.1	964.6	1,000.9
1923	1,408.4	2,358.1	1,184.4	2,027.3	2,006.0	2,358.1	1,888.6	2,240.7	2,432.8
	1,845.9	1,109.7	2,080.6	2,358.1	2,646.2	2,432.8	1,899.3	2,123.3	2,411.4
	1,579.2	1,323.1	1,376.4	2,059.3	2,048.6	2,315.4	1,771.2	2,070.0	2,048.6
	1,781.9	2,048.6	1,963.3	2,112.7	2,198.0	2,368.7	2,283.4	1,835.2	1,920.6
	1,397.8	1,867.2	2,112.7	2,230.0	2,091.3	2,358.1	2,368.7	1,899.3	2,134.0
Average	1,602.6	1,741.3	1,743.5	2,157.7	1,788.3	2,366.6	2,042.2	2,033.7	2,189.5
1924	1,504.5	1,600.5	1,707.2	1,664.5	1,632.5	1,696.5	1,653.8	1,312.4	1,568.5
	1,675.2	1,493.8	1,931.3	1,995.3	1,739.2	1,995.3	1,707.2	1,707.2	1,728.5
	1,685.9	1,483.1	1,568.5	1,632.5	1,525.8	1,632.5	1,493.8	1,621.8	1,312.4
	1,461.8	1,440.4	1,707.2	1,675.2	1,301.7	1,888.6	1,547.1	1,376.4	1,632.5
	1,632.5	1,909.9	1,707.2	1,675.2	1,728.5	1,771.2	1,515.1	1,984.6	1,483.1
Average	1,592.0	1,585.5	1,724.3	1,728.5	1,585.5	1,796.8	1,583.4	1,600.5	1,545.0
1925	1.92	0.21	11.2	294.5	305.2	672.7	1.92	0.00	1.28
	0.75	2.24	5.66	405.5	609.8	642.3	80.56	1.17	0.00
	1.01	7.26	117.9	181.4	136.6	989.6	60.82	0.00	1.03
	2.24	22.30	57.72	961.3	752.8	1,198.8	28.49	0.00	0.43
	251.81	44.81	242.21	314.2	691.4	1,241.4	62.42	0.00	9.82
Average	51.54	15.36	86.94	431.4	499.2	949.0	46.84	0.23	2.51
Grand total	20,809.2	21,640.7	23,332.5	28,671.9	27,175.4	32,252.0	23,302.7	22,995.0	23,689.3
Average	1,040.5	1,082.0	1,166.6	1,433.6	1,358.8	1,612.6	1,165.1	1,149.7	1,184.5

TABLE 4.—*Odds showing the significance of the difference in yield between the residual plats following differently treated plats, calculated by Student's method.*

Differences between irrigations at	Odds that the differences are significant for				
	Grain yield	Straw yield	Combined grain yield	Combined straw yield	Combined grain and straw yield
Germination and tillering	2.45 to 1	10.00 to 1	4.21 to 1	over 10,000.00 to 1	40.70 to 1
Germination and jointing	96.90 to 1	434.00 to 1	795.00 to 1	4,999.00 to 1	over 10,000.00 to 1
Germination and heading	over 10,000.00 to 1	over 10,000.00 to 1	over 10,000.00 to 1	over 10,000.00 to 1	9,999.00 to 1
Germination and blossoming	243.00 to 1	2,531.00 to 1	over 10,000.00 to 1	over 10,000.00 to 1	624.00 to 1
Germination and filling	9,999.00 to 1	over 10,000.00 to 1	over 10,000.00 to 1	932.00 to 1	2,332.00 to 1
Germination and distributed	27.70 to 1	35.00 to 1	over 10,000.00 to 1	over 10,000.00 to 1	9,999.00 to 1
Germination and no irrigation	24.30 to 1	66.60 to 1	less than 2.00 to 1	9.40 to 1	less than 1.96 to 1
Germination and keep growing	24.30 to 1	5.70 to 1	9.40 to 1	6.49 to 1	2.25 to 1
Tillering and jointing	5.00 to 1	3.80 to 1	47.40 to 1	1.92 to 1	15.20 to 1
Tillering and heading	10,000.00 to 1	over 10,000.00 to 1	over 10,000.00 to 1	17.70 to 1	795.00 to 1
Tillering and blossoming	249.00 to 1	over 10,000.00 to 1	681.00 to 1	3.17 to 1	812.00 to 1
Tillering and filling	over 10,000.00 to 1	over 10,000.00 to 1	2,999.00 to 1	2.06 to 1	41.40 to 1
Tillering and distributed	10.80 to 1	less than 2.00 to 1	over 10,000.00 to 1	over 10,000.00 to 1	2,320.00 to 1
Tillering and no irrigation	5.30 to 1	8.70 to 1	2.93 to 1	132.00 to 1	28.00 to 1
Tillering and keep growing	8.10 to 1	3.50 to 1	7.59 to 1	4,999.00 to 1	10.70 to 1
Jointing and heading	over 10,000.00 to 1	1,110.00 to 1	17.70 to 1	16.50 to 1	17.70 to 1
Jointing and blossoming	76.60 to 1	42.50 to 1	less than 2.00 to 1	5.94 to 1	2.54 to 1
Jointing and filling	over 10,000.00 to 1	over 10,000.00 to 1	4.80 to 1	less than 1.92 to 1	less than 1.92 to 1
Jointing and distributed	2.00 to 1	2.50 to 1	2.80 to 1	2,499.00 to 1	738.00 to 1
Jointing and no irrigation	2.00 to 1	2.30 to 1	2,166.00 to 1	335.00 to 1	516.80 to 1
Jointing and keep growing	2.00 to 1	66.60 to 1	3.90 to 1	9,999.00 to 1	2,330.00 to 1
Heading and blossoming	15.10 to 1	9.40 to 1	517.00 to 1	5,999.00 to 1	4,999.00 to 1
Heading and filling	137.00 to 1	46.40 to 1	less than 2.00 to 1	46.70 to 1	27.40 to 1
Heading and distributed	over 10,000.00 to 1	over 10,000.00 to 1	2.25 to 1	47.40 to 1	24.80 to 1
Heading and no irrigation	over 10,000.00 to 1	62.40 to 1	over 10,000.00 to 1	over 10,000.00 to 1	over 9,999.00 to 1
Heading and keep growing	1,000.00 to 1	10,000.00 to 1	44.10 to 1	over 10,000.00 to 1	over 9,999.00 to 1
Blossoming and filling	over 10,000.00 to 1	117.00 to 1	31.20 to 1	31.20 to 1	41.40 to 1
Blossoming and distributed	328.00 to 1	1,000.00 to 1	162.00 to 1	8,999.00 to 1	over 9,999.00 to 1
Blossoming and no irrigation	380.00 to 1	15.20 to 1	over 10,000.00 to 1	81.80 to 1	4,999.00 to 1
Blossoming and keep growing	302.00 to 1	3,332.00 to 1	3.65 to 1	over 10,000.00 to 1	516.80 to 1
Filling and distributed	over 10,000.00 to 1	over 10,000.00 to 1	4.21 to 1	844.00 to 1	513.00 to 1
Filling and no irrigation	over 10,000.00 to 1	750.00 to 1	over 10,000.00 to 1	1,554.00 to 1	over 9,999.00 to 1
Filling and keep growing	over 10,000.00 to 1	over 10,000.00 to 1	11.30 to 1	over 10,000.00 to 1	666.00 to 1
Distribution and no irrigation	2.00 to 1	50.40 to 1	over 10,000.00 to 1	over 10,000.00 to 1	over 9,999.00 to 1
Distribution and keep growing	2.00 to 1	5.70 to 1	140.00 to 1	over 10,000.00 to 1	over 10,000.00 to 1
No irrigation and keep growing	3.50 to 1	39.00 to 1	15.20 to 1	6.49 to 1	less than 1.96 to 1

TABLE 5.—*Yield of straw in pounds per acre on the residual plats for a four-year period, 1922–1925, inclusive.*

Year	Germination	Tillering	Jointing	Heading	Blossoming	Filling	Distributed	No irrigation	Keep growing
1922	853.6	1,248.4	1,600.5	1,611.2	1,664.5	1,941.9	1,163.0	1,365.8	1,099.0
	1,269.7	1,653.8	1,717.9	1,984.6	1,643.2	2,198.0	1,461.8	1,248.4	1,419.1
	1,429.8	1,323.1	1,547.1	2,059.3	1,536.5	2,112.7	1,280.4	1,483.1	1,312.4
	1,355.1	1,376.4	1,835.2	2,091.3	1,653.8	2,102.0	1,355.1	1,408.4	1,451.1
	1,429.8	1,632.5	1,429.8	2,198.0	1,941.9	1,845.9	1,547.1	1,408.4	1,141.7
Average	1,267.6	1,446.8	1,626.1	1,988.9	1,688.0	2,040.1	1,361.5	1,382.8	1,284.7
1923	1,440.4	3,851.9	1,632.5	3,339.7	4,001.2	3,489.1	2,400.7	2,987.6	2,176.7
	2,219.4	2,091.3	2,795.5	2,987.6	3,008.9	3,190.3	3,233.0	2,848.9	2,827.5
	1,952.6	1,579.2	1,941.9	2,656.8	2,358.1	2,635.5	2,304.7	2,400.7	1,792.6
	2,347.4	2,635.4	1,984.6	2,614.1	2,432.8	2,912.9	2,560.8	4,214.6	2,475.4
	1,664.5	2,187.3	2,667.5	3,094.3	2,838.2	2,848.9	2,934.2	2,635.5	2,646.2
Average	1,924.9	2,469.0	2,204.4	2,938.5	2,927.8	3,015.3	2,686.7	3,014.5	2,383.7
1924	2,635.5	2,966.3	3,083.6	3,062.3	2,891.6	2,944.9	2,763.5	2,795.5	2,816.9
	2,976.9	2,710.2	3,563.8	3,489.1	3,243.7	3,617.1	3,190.3	2,987.6	3,158.3
	3,019.6	2,742.2	2,827.5	2,934.2	2,838.2	2,944.9	2,560.8	2,827.5	2,464.8
	2,667.5	2,560.8	2,848.9	3,019.6	2,667.5	3,435.7	2,635.5	2,411.4	2,848.8
	2,870.2	3,275.7	3,147.6	2,859.6	2,966.3	3,137.0	2,582.1	3,489.1	2,560.8
Average	2,833.9	2,309.0	3,094.3	3,073.0	2,921.5	3,215.9	2,746.4	2,905.5	2,769.9
1925	30.73	15.36	84.83	367.0	493.0	958.2	30.62	8.54	17.6
	17.07	37.13	35.96	586.8	756.0	1,112.3	132.84	260.35	41.3
	35.74	27.00	212.87	298.8	332.9	1,355.6	46.73	15.79	46.5
	32.22	41.72	112.46	1,176.9	879.7	1,404.7	59.33	39.27	42.3
	303.0	147.78	280.62	422.0	887.7		70.96	48.55	31.1
Average	83.75	53.80	145.35	570.3	669.9	1,207.7	68.1	74.5	35.74
Grand total	30,550.73	34,103.49	35,350.64	42,853.2	41,035.7	46,187.6	34,313.48	36,885.0	32,370.02
Average	1,527.5	1,705.1	1,767.5	2,142.7	2,051.8	2,430.9	1,715.6	1,844.2	1,618.5

plats after a "distributed" irrigation, those after "no irrigation," and the "keep growing" plats was 193.7 pounds, 209.1 pounds, and 174.3 pounds, respectively, in favor of the residual plats irrigated at "blossoming."

The residual plats irrigated the previous year at "filling" outyielded the residual plats following a "distributed" irrigation, those after "no irrigation," and after those receiving enough water to "keep growing" by 447.5 pounds, 462.9 pounds, and 428.1 pounds, respectively. The differences between the residual plats irrigated the previous year at "tillering" and at "jointing" and after those receiving a "distributed" irrigation, those receiving sufficient water to "keep growing," and the "no irrigation" plats were so small that the chances that the differences were significant were less than 10.8 to 1.

The residual plats after a "distributed" irrigation outyielded the residual plats after those irrigated at "germination" by 124.6 pounds. The residual "no irrigation" plats outyielded the residual plats after those irrigated at "germination" by 109.2 pounds. A difference of 144.0 pounds was found between the residual plats receiving enough water the previous year to keep them growing and the residual plats irrigated the previous year at "germination." The residual "keep growing" plats outyielded the residual "germination" plats, but the odds that the difference was significant were 2.45 to 1. The residual plats irrigated the previous year at "jointing" outyielded the residual plats irrigated at "germination" by 126.1 pounds. The difference of 84 pounds between the residual plats irrigated the previous year at "jointing" and those irrigated at "tillering" was in favor of the residual plats irrigated at "jointing." The odds that this difference was significant were 5 to 1.

In summing up the above data, it will be seen that the plats irrigated at "heading," "blossoming," or "filling" in the preceding year outyielded the plats irrigated at any other time.

YIELD OF STRAW

Table 5 gives the straw yield in pounds per acre for the residual crops. The residual plats irrigated the previous year at "heading," "blossoming," or "filling" gave the highest yields of straw. The residual plats irrigated the previous year at "tillering" outyielded the residual plats irrigated the previous year at "germination" by 177.6 pounds, odds of 10 to 1. The residual plats irrigated the previous year at "heading" outyielded the residual plats irrigated at "germination" by 715.2 pounds. The difference between the residual plats irrigated at "blossoming" and the residual plats irrigated at "germination" was 524.3 pounds in favor of the former. The residual plats irrigated at "filling" outyielded the residual plats irrigated at "germination" by 903.4 pounds. The residual plats irrigated the previous year at "germination" yielded 188.1 pounds less than the residual plats which received a "distributed" irrigation. The residual plats which received "no irrigation" outyielded the residual plats irrigated at "germination" by 316.7 pounds. The residual plats which received enough water to keep them growing outyielded the residual plats irrigated at "germination" by 91.0 pounds, odds 5.7 to 1.

When the residual plats irrigated at "tillering" were compared with the residual plats irrigated at "jointing" there was a difference of 62.4 pounds in favor of the latter, odds of 3.8 to 1. The residual plats irrigated at "tillering" yielded less than the residual plats irrigated at "heading," "blossoming," and "filling." The differences were 437.6 pounds, 346.7 pounds, and 725.8 pounds, respectively. The residual plats irrigated at "tillering" yielded less than the residual plats which received a "distributed" irrigation, and those which received "no irrigation." The odds that the differences were significant were very small. The residual plats irrigated at "tillering" outyielded the residual plats which received enough water to keep them growing by 86.6 pounds, odds 3.5 to 1.

The residual plats irrigated the previous year at "jointing" yielded 375.2 pounds less than the residual plats irrigated at "heading," odds of 1,110 to 1. The residual plats irrigated at "blossoming" outyielded the residual plats irrigated at "jointing" by 284.3 pounds, odds of 42.5 to 1. The residual plats irrigated at "filling" outyielded the residual plats irrigated at "jointing" by 663.4 pounds. The odds that the difference between the residual plats irrigated at "jointing" and the residual plats which received a "distributed" irrigation or "no irrigation" was significant were very small. The residual plats irrigated at "jointing" and the residual plats which received enough water to "keep growing" differed by 149 pounds in favor of the former, odds of 66.6 to 1. There was a difference of 90.9 pounds in favor of the residual plats irrigated at "heading" over the residual plats irrigated at "blossoming." The chances that this difference was significant were 9.4 to 1. Between the residual plats irrigated at "heading" and the residual plats irrigated at "filling" there was a difference of 288.2 pounds in favor of the residual plats irrigated at "filling." The chances that this difference was significant were 46.4 to 1. The residual plats irrigated at "heading" outyielded the residual plats which received a "distributed" irrigation and those which received enough water to "keep growing" by 427.2 pounds and 524.2 pounds, respectively. The residual plats irrigated at "heading" outyielded the "no irrigation" plats by 298.5 pounds. The residual plats irrigated at "filling" outyielded the residual plats irrigated at "blossoming" by 379.1 pounds. The difference between the residual plats irrigated at "blossoming" and the residual plats which received a "distributed" irrigation was 336.2 pounds in favor of the former. The "no irrigation" residual plats yielded 207.6 pounds less than the residual plats irrigated at "blossoming," odds of 15.2 to 1. The residual plats irrigated at "blossoming" outyielded the residual plats which received enough water to "keep growing" by 433.3 pounds. The residual plats irrigated at "filling" outyielded the residual plats which received a "distributed" irrigation, "no irrigation," or sufficient water to "keep growing." The "no irrigation" residual plats outyielded the residual plats receiving a "distributed" irrigation by 128.6 pounds, odds of 50.4 to 1.

The yield of the "no irrigation" residual plats was 225.7 pounds greater than the yield of the "keep growing" residual plats. The chances that this difference was significant were 39.0 to 1.

Summing up clearly shows that the residual plats receiving a late irrigation the previous year at "heading," "blossoming," or "filling" outyielded residual plats irrigated at "germination," "tillering," or "jointing."

YIELD OF GRAIN FROM CRITICAL PERIOD AND RESIDUAL PLATS

The grain yields from the critical period treatments were combined with the grain yields from the same plats in the following year. Table 6 gives the yields in pounds per acre of the differently treated plats by two-year periods from the years 1921 to 1925, inclusive. The highest yielding plats were the ones receiving a "distributed" irrigation. However, they outyielded the plats which received an irrigation at "heading" by 38.6 pounds, odds of 2.25 to 1. The plats receiving a "distributed" irrigation outyielded the plats irrigated at "filling" by 81.4 pounds, odds of 4.21 to 1. The "distributed" plats outyielded the "blossoming" plats by 212.8 pounds, odds of 162 to 1. The plats irrigated at "jointing" were outyielded by the plats receiving a "distributed" irrigation by 38.6 pounds, odds of 2.8 to 1. The difference between the plats receiving a "distributed" irrigation and the plats irrigated at "germination," "tillering," and those receiving "no irrigation" were 586.2 pounds, 514.9 pounds, and 564.2 pounds, respectively, in favor of the plats re-

TABLE 6.—*Combined grain yield in pounds per acre for two-year periods from the critical period and the residual plats which followed.*

Year	Germination	Tillering	Jointing	Heading	Blossoming	Filling	Distributed	No irrigation	Keep growing
1921–22	1,108.7	1,302.9	3,121.0	1,660.9	1,611.9	1,361.4	1,681.6	1,159.8	1,326.8
	1,267.0	1,450.0	1,702.5	1,904.2	1,432.1	1,730.0	1,530.5	976.3	1,429.1
	1,526.5	1,405.7	1,476.1	1,839.2	1,501.3	1,649.7	1,726.2	1,152.9	1,484.9
	1,692.9	1,425.8	1,854.0	1,864.2	1,504.8	1,634.5	1,474.7	1,345.2	1,356.0
	1,535.8	1,507.0	1,511.8	2,210.6	1,864.1	1,617.0	1,710.7	1,208.2	1,427.3
Average	1,426.2	1,418.3	1,933.1	1,895.8	1,582.8	1,598.5	1,624.7	1,168.5	1,404.8
1922–23	1,988.2	3,158.7	2,134.8	2,758.8	2,658.8	2,920.1	2,983.0	2,736.1	2,910.9
	2,535.2	1,991.0	2,783.3	3,185.6	3,274.0	2,964.6	3,089.7	2,580.3	2,922.1
	2,107.2	1,960.5	2,159.8	2,827.3	2,699.5	2,835.7	2,953.9	2,519.3	2,601.6
	2,611.3	2,703.3	2,723.6	2,815.4	2,772.1	2,898.6	3,322.1	2,248.0	2,398.7
	2,046.8	2,466.2	2,815.4	3,078.6	2,771.0	2,801.6	3,374.8	2,344.7	4,964.7
Average	2,257.7	2,455.9	2,523.4	2,933.1	2,835.1	2,884.1	3,144.7	2,485.7	3,159.6
1923–24	2,406.9	2,585.5	2,863.0	2,764.7	2,584.8	2,474.1	3,260.8	2,262.8	2,655.2
	2,671.7	2,570.9	3,150.5	3,231.8	2,751.0	2,840.1	3,283.5	2,795.8	2,711.5
	2,519.2	2,564.1	2,707.1	2,730.7	2,462.8	2,346.7	2,893.5	2,589.5	2,374.2
	2,385.3	2,104.7	2,742.1	2,692.8	2,184.9	2,564.4	2,962.1	2,367.1	2,448.5
Average	2,495.8	2,456.3	2,865.7	2,855.0	2,495.9	2,556.3	3,099.9	2,503.8	2,547.3
1924–25	1,080.9	1,056.2	1,297.6	1,546.3	1,474.5	1,847.7	1,511.0	1,249.9	1,040.0
	1,075.8	1,213.7	1,399.6	1,755.1	1,784.8	1,796.2	1,537.8	1,030.3	1,123.2
	845.8	1,034.5	1,243.0	1,458.2	1,426.8	2,343.2	1,833.0	1,246.1	1,010.9
	944.9	1,043.1	1,209.7	2,084.5	1,914.4	2,252.9	1,610.6	1,067.5	998.8
	1,065.9	1,225.6	1,371.1	1,410.5	1,835.7	2,128.4	1,813.4	954.2	1,050.4
Average	1,002.6	1,114.6	1,304.2	1,650.9	1,687.2	2,073.7	1,661.2	1,109.6	1,044.6
Grand total	33,416.03	34,769.41	40,265.96	43,819.4	40,509.3	43,006.9	44,553.01	34,833.97	38,234.84
Average	1,758.7	1,830.0	2,119.3	2,306.3	2,132.1	2,263.5	2,344.9	1,780.7	2,012.4

ceiving a "distributed" irrigation. The odds that the above differences were significant were over 10,000 to 1.

The plats receiving a "distributed" irrigation outyielded the "keep growing" plats by 332.5 pounds,[4] odds of 140 to 1.

The plats irrigated at "jointing" outyielded the plats irrigated at "germination" by 360.6 pounds. The plats irrigated at "jointing" outyielded the plats irrigated at "tillering" by 79.3 pounds. The differences between the plats irrigated at "jointing" and the plats irrigated at "heading," "blossoming," "filling," and the "distributed" irrigation plats were 187.0 pounds, 12.8 pounds, 144.2 pounds, and 225.6 pounds, respectively, greater than the yield of the plats irrigated at "jointing." The chances that these differences were significant were 17.7 to 1, less than 2 to 1, 4.8 to 1, and 2.8 to 1, respectively. The plats irrigated at "jointing" outyielded the plats receiving "no irrigation" by 338.6 pounds.

The difference between the plats irrigated at "heading" and the plats irrigated at "filling" was 42.8 pounds in favor of the former. The chances that this difference was significant were less than 2 to 1. The plats irrigated at "heading" outyielded the plats irrigated at "blossoming" by 174.2 pounds. The "no irrigation" plats yielded 525.6 pounds less than the plats irrigated at "heading." The plats irrigated at "heading" outyielded the "keep growing" plats by 293.9 pounds. The plats irrigated at "heading" outyielded the plats irrigated at "germination" or "tillering."

The difference in yield between the plats irrigated at "blossoming" and the plats irrigated at "germination" was 373.4 pounds in favor of the former. The plats irrigated at "blossoming" outyielded the plats receiving "no irrigation" by 351.3 pounds. The "tillering" plats yielded 302 pounds less than the "blossoming" plats. The plats irrigated at "blossoming" outyielded the "keep growing" plats by 119.7 pounds, odds of 3.65 to 1.

The plats irrigated at "filling" outyielded the plats irrigated at "germination" and "tillering" by 504.8 and 373. 5 pounds, respectively. The "filling" plats outyielded the "keep growing" plats by 251.1 pounds, odds of 11.3 to 1. The difference between the plats irrigated at "germination" and the plats irrigated at "tillering" was 71.3 pounds in favor of the latter, odds of 4.2 to 1.

The differences between the plats irrigated at "germination" and the plats receiving "no irrigation" or the "keep growing" plats were small. The odds that the differences were significant were less than 9.5 to 1. Similar differences were found for the "keep growing" plats and the "no irrigation" plats. The "keep growing" plats slightly outyielded the "tillering" plats, while the "no irrigation" plats yielded slightly less than the "tillering" plats. The odds were small.

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[4] Moisture drifted onto the "keep growing" plats during the season of 1923 (3) and 1924 (unpublished data).

In summing up, the fact must be taken into consideration that rain drifted onto the "no irrigation" and "keep growing" plats in 1923. However, from the above discussion it will be seen that when the yields of the two years of cropping were combined, the difference between the plats irrigated in the periods from "jointing" to "filling" was lessened.

"Distributed" irrigation gave a high yield. But the residual effect was a low yield the following year. Irrigation at "blossoming" and "filling" gave a lower yield than "distributed" irrigation. But the residual plats the following year yielded higher. The plats irrigated at "heading" yielded well both years. The plats irrigated at "jointing" yielded well the year they were irrigated but benefited very little from this moisture in the following year. The earlier irrigations did not give any significant increase over the check plats which received "no irrigation."

YIELD OF STRAW FROM CRITICAL PERIOD AND FOLLOWING RESIDUAL PLATS

The straw yield of the critical period and residual plats was combined in the same way as the grain yields. Table 7 gives the combined straw yields for a five-year period, 1921 to 1925, and Table 4 gives the chances that the differences were significant. It will be seen from Table 7 that the plats receiving a "distributed" irrigation outyielded all other plats. The nearest competitor, the plats irrigated at "heading," yielded 345.2 pounds less. The plats receiving "distributed" irrigation outyielded the plats irrigated at "germination" by 1,132.9 pounds. The plats irrigated at "tillering" yielded 616.5 pounds less than the plats receiving a "distributed" irrigation.

The plats receiving a "distributed" irrigation outyielded the plats irrigated at "jointing" by 541.2 pounds. The "distributed" irrigation plats yielded 616.5 pounds more than the plats irrigated at "tillering." The "distributed" irrigation plats outyielded the plats receiving enough water to "keep growing" and the "no irrigation" plats by 1,243.3 pounds and 1,045.6 pounds, respectively.

The plats irrigated at "heading" outyielded the plats irrigated at "jointing" by 196 pounds and the plats irrigated at "filling"[5] by

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[5] All averages compared with the plats irrigated at "filling" are the averages of 18 plats. In thrashing the yield of straw was omitted for one plat.

TABLE 7.—*Combined straw yield in pounds per acre for two-year periods for the critical period and the residual plats which follow*

Year	Germination	Tillering	Jointing	Heading	Blossoming	Filling	Distributed	No irrigation	Keep growi
1921–22	2,554.2	3,302.8	2,921.5	2,709.4	2,655.2	2,740.6	2,841.1	1,962.9	2,047.5
	2,565.7	2,469.2	3,290.4	3,032.9	2,211.5	2,780.0	2,585.0	1,713.0	2,167.9
	2,871.7	2,444.4	3,726.0	2,950.2	2,579.1	2,848.1	2,989.2	1,809.5	2,558.5
	3,136.9	3,118.2	3,150.4	3,220.3	2,784.7	3,125.4	2,635.7	2,138.0	2,482.1
	3,105.0	2,997.6	2,660.5	3,906.8	3,180.3	2,790.5	2,916.1	2,026.6	2,309.1
Average	2,846.7	2,866.4	2,949.7	3,163.9	2,682.2	2,874.9	2,793.4	1,930.0	2,313.0
1922–23	2,484.9	5,658.6	3,456.5	4,731.7	5,170.5	4,618.1	4,017.3	3,974.5	3,177.0
	3,578.8	3,715.6	4,101.1	4,327.8	4,018.8	4,194.5	5,446.8	3,649.5	3,728.0
	3,020.1	2,833.0	3,393.4	3,968.2	3,402.6	3,480.3	4,182.5	3,234.0	2,700.8
	3,572.3	3,983.2	3,317.1	3,766.1	3,362.1	3,909.4	4,250.4	4,976.8	2,423.9
	2,743.5	3,322.0	4,013.4	4,438.3	3,953.7	3,647.6	4,560.4	3,555.2	3,352.8
Average	3,079.9	3,902.5	3,656.3	4,246.4	3,981.5	3,970.0	4,491.5	3,878.0	3,076.5
1923–24	4,605.4	5,107.1	5,525.8	5,151.3	4,640.7	4,519.3	5,785.6	4,515.8	4,786.8
	4,939.1	5,231.1	6,052.1	6,010.1	5,194.4	5,425.7	6,435.1	4,949.8	4,936.2
	4,937.7	5,017.4	5,098.9	4,852.3	4,554.7	4,477.1	5,561.8	4,567.0	4,417.4
	4,301.4	5,697.9	5,079.9	4,989.5	4,309.1	4,635.7	5,442.5	4,183.6	4,357.9
Average	4,695.9	5,263.4	5,439.2	5,250.8	4,674.7	4,764.4	5,806.2	4,554.0	4,624.5
1924–25	1,701.1	2,106.3	2,486.7	2,375.3	2,198.0	2,663.2	3,473.2	2,339.4	1,954.9
	1,902.5	2,581.1	2,530.1	2,754.4	2,601.1	2,924.8	3,335.4	2,197.7	2,000.2
	1,398.9	2,008.4	3,290.7	2,643.1	2,606.2	3,227.6	4,011.5	2,448.4	1,741.9
	1,608.5	2,197.9	2,266.7	3,131.5	2,592.3	2,741.0	3,667.0	2,039.9	1,687.7
	1,503.0	2,549.7	2,411.8	2,537.8	2,800.0		3,918.7	1,907.2	1,601.7
Average	1,622.8	2,288.7	2,597.2	2,688.4	2,559.5	2,889.1	3,681.2	2,186.5	1,797.3
Grand total	56,530.7	66,341.5	67,773.0	71,497.0	64,815.0	64,838.9	78,055.4	58,188.8	54,432.3
Average	2,975.3	3,491.7	3,567.0	3,763.0	3,411.3	3,602.2	4,108.2	3,062.6	2,864.9
Average 18 plats	3,140.6	3,544.0	3,631.2	3,831.1	3,445.3	3,602.2	4,118.7	3,126.8	2,935.0

228.9 pounds. The odds that these differences were significant were 16.5 to 1 and 46.7 to 1, respectively. The difference in yield between the plats irrigated at "blossoming" and the plats irrigated at "heading" was 351.7 pounds. The plats irrigated at "heading" outyielded the plats irrigated at "tillering" by 272 pounds, odds of 17.7 to 1. The "heading" plats yielded 787.7 pounds more than the plats irrigated at "germination," 700.4 pounds more than the "no irrigation" plats, and 898.1 pounds more than the "keep growing" plats. There was a difference of 29 pounds between the plats irrigated at "jointing" and the plats irrigated at "filling," odds of less than 1.92 to 1. The "jointing" plats yielded the highest. The difference between the plats irrigated at "jointing" and at "tillering" was 75.3 pounds in favor of the "jointing" plats, odds of 1.92 to 1. The plat irrigated at "jointing" outyielded the plat irrigated at "blossoming" by 155.7 pounds, odds of 5.94 to 1. The "jointing" plats yielded 591.7 pounds more than the "germination" plats. The "no irrigation" plat yielded 504.4 pounds less than the plat irrigated at "jointing." The plats irrigated at "jointing" outyielded the "keep growing" plats 702.1 pounds.

The plats irrigated at "filling" outyielded the plats irrigated at "tillering" by 58.2 pounds, odds of 2.06 to 1. The difference between the "filling" and "blossoming" plats was 156.9 pounds in favor of the former. The odds that this difference was significant were 31.2 to 1. The plats irrigated at "filling" outyielded the plats irrigated at "germination" by 461.6 pounds. The "no irrigation" plats yielded 475.4 pounds less than the plats irrigated at "filling." The plats irrigated at "filling" outyielded the "keep growing" plats 667.2 pounds. The plats next in yield to the plats irrigated at "filling" were those irrigated at "tillering." The plats irrigated at "tillering" outyielded the plats irrigated at "blossoming" by 80.4 pounds, odds of 3.17 to 1. The difference in yield between the plats irrigated at "tillering" and the "no irrigation" plats was 429.1 pounds in favor of the former. The plats irrigated at "tillering" outyielded the "keep growing" plats 626.8 pounds.

The plats irrigated at "blossoming" outyielded the plats receiving "no irrigation" by 318.5 pounds. The "keep growing" plats yielded 546.4 pounds less than the plats irrigated at "blossoming." The differences between the plats irrigated at "germination" and the plats receiving "no irrigation" or the "keep growing" plats were small. The odds that these differences were significant were less than 9.40 to 1.

Summing up, the above data show that the plats irrigated at

TABLE 8.—*Combined yield of grain and straw in pounds per acre for two years from the critical period and the residual plats which follow.*

Year	Germination	Tillering	Jointing	Heading	Blossoming	Filling	Distribution	No irrigation	Keep growing
1921–22	3,662.9	4,605.7	6,042.5	4,370.3	4,267.1	4,102.0	45,22.7	3,122.7	3,374.3
	3,832.7	3,919.2	4,992.9	4,937.1	3,643.6	4,600.0	4,115.5	2,689.3	3,597.0
	4,398.2	3,850.1	4,202.1	4,789.4	4,080.4	4,497.8	4,715.4	2,962.4	4,043.4
	4,829.8	4,544.0	5,004.4	5,084.5	4,289.5	4,759.9	4.110.4	3,483.2	3,838.1
	4,640.8	4,505.6	4,172.3	6,117.4	5,044.4	4,407.5	4,626.8	3,234.8	3,736.4
Average	4,272.9	4,284.7	4,882.8	5,059.7	42,65.0	4,473.4	4,418.2	3,098.6	3,717.8
1922–23	4,837.1	8,817.3	5,591.3	7,490.5	7,829.3	7,538.2	7,000.3	6,710.6	6,087.9
	6,114.0	4,706.6	6,884.4	7.513.4	7,292.8	7,159.1	8.536.5	6,229.8	6,650.1
	5.127.3	4,793.5	5,553.2	6,795.5	6,102.1	6,316.0	7,136.4	5,753.3	5,311.4
	6,183.6	6,686.5	6,040.7	6,581.5	6,134.2	6,808.0	7,572.5	7,224.8	4,822.6
	4.790.3	5,788.2	6,828.8	7.516.9	6,724.7	6,449.2	7,935.2	5,899.9	8,317.5
Average	5,410.5	6,158.4	6,179.9	7,179.6	6,816.4	6,854.1	7,638.2	6,363.7	6,237.9
1923–24	7,012.3	7,692.6	8,388.8	7,916.0	7,225.5	6,993.4	9,046.4	6,778.6	7,442.0
	7,610.8	7,802.0	9,202.6	9,241.9	7,945.4	8,265.8	9,718.6	7,745.6	7,647.7
	7,456.9	7,581.5	7,806.0	7,583.0	7,017.5	6,823.8	8,455.3	7,156.5	6,791.6
	6,686.7	7,802.6	7,822.0	7,682.3	6,494.0	7,200.1	8,404.6	6,550.7	6,806.4
Average	7,191.7	6,219.7	8,804.8	8,105.8	7,170.6	7,320.8	8,906.2	7,057.8	7,171.9
1924–25	2,784.0	3,162.5	3,784.3	3,921.6	3,672.5	4,480.9	4,984.2	3.589.3	2,994.9
	2,978.2	3,794.8	3,929.7	4.509.5	4,385.9	4,721.0	4,873.3	3,227.9	3,123.4
	2,244.7	3,042.9	4,533.7	4,101.3	4,033.0	5.570.8	5,844.5	3,692.5	2,752.8
	2.553.4	3,241.0	3,476.4	5,216.0	4,506.7	4,993.9	5,277.6	3,107.4	2,686.5
	2,568.9	3,775.3	3,782.9	3,948.3	4,635.7		5,732.1	2,861.4	2,652.1
Average	2,625.8	3,403.3	3.901.4	4.339.3	4,246.8	4,941.7	5,342.5	3,296.1	2,851.9
Grand total	90,312.6	100,110.91	108,039.0	115,316.4	105,324.3	105,687.4	122,608.3	92,022.7	92,676.1
Average	4,753.3	5,269.0	5,686.3	6,069.3	5,543.4	5,871.5	6,453.1	4,843.3	4,877.7
Average 18 plats	4,874.6	5,352.0	5,792.0	6,187.1	5,593.8	5,871.5	6,493.1	4,953.4	5,001.3

"heading," "filling," and those receiving a "distributed" irrigation gave the highest yield of straw when both the critical period and residual plats were combined.

SOIL MOISTURE

In studying the effect of previous irrigations on the following crop, soil moisture determinations were made on all plats after harvesting the grain and straw. The moisture content varied little in the replication of each treatment. However, there was a marked difference in the moisture content of the different treatments. Table 9 gives the average moisture content at the end of the season for each treatment for a four-year period, 1921 to 1924, inclusive. Table 9 shows that the soil moisture content was highest in the plats receiving an irrigation at "filling." The moisture content varied with the other treatments. The crops on the earlier irrigated plats drew heavily on the moisture of the first 3 feet of soil. The fifth foot varied slightly and was fairly uniform throughout all treatments. The moisture samples were taken in 6-inch sections for the first foot and 1-foot sections thereafter.

The soil was drier after the early irrigations and wetter after the later irrigations and continued to increase in moisture content as the irrgiations were later in the development of the crop. The plats irrigated at "germination," those receiving "no irrigation," and the "keep growing" plats had the lowest percentage of moisture at the end of the season in the first 3 feet of soil. The fourth foot in the soils of the "germination," "no irrigation," and "keep growing" plats was somewhat lower in moisture content than was the fourth foot of the later treatments. The plats receiving a "distributed" irrigation were slightly higher in moisture in the second foot section than the plats receiving "no irrigation," those receiving sufficient moisture to "keep growing," and those irrigated at "germination." The other sections of the soil from the distributed plats to a depth of 5 feet were similar in moisture content to the plats irrigated at "germination," those receiving "no irrigation," and the "keep growing" plats. It will be noticed that there was a slight increase in the moisture content of the first 3 feet up until the time of "heading." There was an increase of the moisture left in the soil in the first 6 inches, the second 6 inches, and the second foot up until the time of "filling." The third foot section increased very slightly in the plats irrigated after "heading."

In conclusion, it is seen that the moisture content of the soil increased as the time of irrigation advanced towards the "filling" stage. The later in the stage of development of the plant that a 6-inch irrigation was applied, the higher was the moisture content of the soil in the fall.

RAINFALL AND SOIL MOISTURE

Cole and Mathews (2) state that, "The quantity of stored water is of importance in determining yields. *** Comparison of two plats each year showed that the plat having the greater moisture content about May 1, gave the higher yield in 73 out of 93 cases. Very little correlation existed between the quantity of moisture stored and the yield in different years of the same plat. In other words, it was not possible to prove that 6 inches of stored water in the soil of a plat in one year was any more effectual in producing a good yield than 4 inches of water might be in another year. The precipitation was the deciding factor. However, when two plats were compared for the same year the plat having the greater quantity of stored water present was fairly certain to produce the higher yield. A plat with 6 inches of stored water available was almost certain to produce a higher yield of grain than one having 4 inches of water. While the precipitation for the growing season is the deciding factor in wheat production, the quantity of stored water supplementing the rainfall has a decided bearing upon the yield of the crop."

TABLE 9.—*Percentage of soil moisture in critical period plats in the fall for the years 1921–1924, inclusive.*[a]

Depth of soil	1921	1922	1923	1924
	Germination			
1 to 6 inches	4.664	4.488	4.173	4.980[b]
7 to 12 inches	6.588	7.207	6.437	
2 feet	8.118	8.415	8.253	8.262
3 feet	11.628	11.069	12.467	10.907
4 feet	11.468	11.879	13.064	13.303
5 feet	11.070	12.436	13.122	14.452
	Tillering			
1 to 6 inches	4.402	4.806	4.654	5.077
7 to 12 inches	7.235	7.763	6.276	
2 feet	10.093	9.209	9.154	7.980
3 feet	11.666	11.847	11.477	10.157
4 feet	10.977	12.467	12.709	11.969
5 feet	11.196	11.720	13.113	14.818
	Jointing			
1 to 6 inches	4.305	5.163	4.635	5.056
7 to 12 inches	8.378	7.779	7.166	
2 feet	11.709	10.659	9.811	9.756

[a] Percentages are the average of five plats.

[b] First foot.

TABLE 9.—*continued.*

Depth of soil	1921	1922	1923	1924
Jointing				
3 feet	13.223	12.647	13.769	12.581
4 feet	11.440	12.359	13.122	13.183
5 feet	10.582	12.686	13.589	14.454
Heading				
1 to 6 inches	6.253	5.797	5.056	5.884
7 to 12 inches	10.200	10.259	7.690	
2 feet	12.319	13.937	11.656	12.627
3 feet	12.499	14.173	14.105	13.993
4 feet	12.286	13.029	12.942	13.205
5 feet	10.720	12.193	13.476	14.529
Blossoming				
1 to 6 inches	5.950	6.852	6.067	6.367
7 to 12 inches	11.498	12.310	13.168	
2 feet	13.767	13.754	14.487	13.863
3 feet	13.705	13.860	14.367	14.071
4 feet	12.246	12.221	13.646	12.750
5 feet	11.357	12.137	13.099	14.023
Filling				
1 to 6 inches	8.743	9.576	10.386	8.219
7 to 12 inches	13.615	13.934	14.659	
2 feet	14.648	15.275	17.132	14.972
3 feet	13.219	14.438	16.746	14.111
4 feet	11.877	13.279	14.526	13.090
5 feet	11.027	13.007	13.759	14.371
Distributed				
1 to 6 inches	5.204	5.569	6.030	5.237
7 to 12 inches	8.012	7.881	7.996	
2 feet	9.787	8.639	9.328	8.423
3 feet	11.689	11.882	12.029	9.038
4 feet	10.961	11.342	12.269	12.232
5 feet	9.894	12.025	12.120	14.061
No irrigation				
1 to 6 inches	3.781	4.461	3.908	4.375
7 to 12 inches	6.954	7.132	5.805	
2 feet	9.954	8.960	7.311	7.569
3 feet	11.744	12.078	10.002	7.916
4 feet	10.837	11.801	12.011	11.082
5 feet	10.447	11.986	12.442	13.276
Keep growing				
1 to 6 inches	4.165	4.495	4.585	4.737
7 to 12 inches	6.876	6.722	6.054	
2 feet	7.968	8.433	7.992	7.610
3 feet	10.390	11.588	10.823	8.357
4 feet	10.006	11.423	11.838	11.584
5 feet	9.920	12.165	13.364	13.767

The effect of the variations in annual rainfall plus the amount of moisture in the soil in the fall of the previous year to which the crop is planted was very marked. The yield of grain on the residual plats, shown in Table 3, varied in the following order. The crop of 1923 was the highest, that of 1924 was next, 1922 next, and 1925 was the lowest.

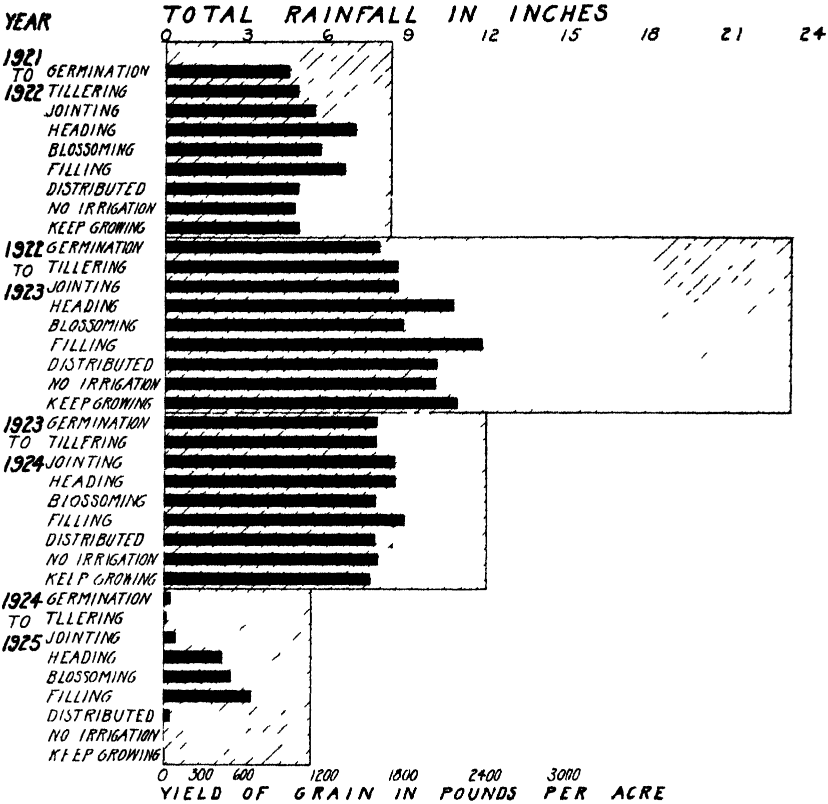

FIG. 2.--Total rainfall and residual yields of grain in pounds per acre for the years 1921 to 1925, inclusive.

A comparison of these yields with rainfall, shown in Table 1, shows that the rainfall decreased in the same order, *viz.*, 1923, 1924, 1922, and 1925

Finally, the amount of precipitation which fell between the harvesting of one crop and the harvesting of the succeeding crop had a marked effect on the yield This is shown graphically in Fig. 2. But the amount of moisture in the soil in the fall also had a marked effect on the yield of the grain. The difference in response of Marquis wheat to different amounts of stored water was reduced as the amount of precipitation in the season increased. Late irrigations had a residual effect on the preceding crop even with 23.26 inches of precipitation from the time one crop was harvested to the time the succeeding crop was harvested. The residual effect of late irrigations on the succeeding crop was more marked when the precipitation was 5.64 inches than when it was 23.26 inches.

Fig. 2 clearly shows the effect of rainfall on the yield of the residual crop. It will be noticed that in three cases out of four the plats irrigated at "blossoming" yielded less than the plats irrigated at "heading." It is shown in Table 9 that this was not caused by a decrease in moisture content of the soil at the end of the season.

SUMMARY

The residual effect of previous irrigations showed up on the following Marquis wheat crop.

Where water was applied late in the growing season, that is at "heading," "blossoming," or "filling," the following crop was influenced more than where water was applied at "germination," "tillering," or where the plats received a "distributed" irrigation.

When the crops of the two years were combined the plats receiving a "distributed" irrigation gave the highest yield of grain and straw. The plats irrigated at "heading" gave the highest yield of the plats receiving a single irrigation of 6 inches.

Soil moisture determinations made at the end of the first season showed that more moisture was left in the first 5 feet of soil when the plats were irrigated at "filling" and that the amount decreased with the earlier application.

The rainfall during the crop year affected the yield but not the ranking of the different treatments. The succeeding crop grown on the plats irrigated at "filling" gave the highest yield whether the rainfall was 5.64 inches or 23.26 inches.

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CROTALARIA AS A SOIL-BUILDING CROP[1]

W. E. Stokes[2]

The Florida Experiment Station, in cooperation with the Office of Forage Crops of the Bureau of Plant Industry, United States Department of Agriculture, is constantly trying out new plants from all parts of the world.

Several years ago the late Dr. C. V. Piper, then Chief of the Office of Forage Crops, had sent to the Florida Station seed of a number of species of Crotalaria in the hope that one or more of them might prove of value to Florida. Observations and experiences with these Crotalarias thus far have led to the belief that at least one species is well worth trying as a cover and land building crop. Several citrus, pecan, and tung oil grove owners of Florida have grown one of these introduced Crotalarias for several years as a grove cover and land building crop with entire satisfaction.

HISTORY OF THE PLANT

Crotalaria, of which there are many species, is a leguminous plant native to Africa, India, South America, Mexico, and the United States. In India and other parts of the Old World, Crotalaria is used as an ornamental garden plant, as well as a cover and green manure crop in coffee and tea plantations. Some species are used for fibre, while the Porto Rico Experiment Station in its annual report for 1921 describes the use of a species of Crotalaria as a forage plant. Australian investigators report some species as valuable soil improvers and some species as poisonous to livestock.

DESCRIPTION OF THE PLANT

Crotalaria striata Schrank., the species that looks most promising from the cover and land building standpoint and which will hereafter in this article be called Crotalaria, is an erect-growing annual plant not unlike beggarweed in its general habit of growth.

The plant has numerous yellow blossoms borne on long terminal racemes. The kidney-shaped seed, which vary in color from olive green to brown, are borne in pods similar to sugar peas and to ordinary rattle box. Crotalaria is closely related to the latter. Each brown to straw-colored pod contains many seed, 40- to 50-odd, which are about the size of the hulled beggarweed seed. The leaf is in three parts, or what the botanists call a "trifoliate leaf" being similar to, but somewhat smaller than, the leaf of the beggarweed. The plant on Norfolk sandy soil has a deep taproot with many fibrous roots, all of which are abundantly supplied with nodules. When thickly planted, little branching takes place, while thin plantings branch freely. The maximum height of a season's growth on the Norfolk sand of the Florida Experiment Station grounds is usually about 6 feet.

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[1] Paper read at the meeting of the Agronomy Section of the Southern Agricultural Workers' Association, February 3, 1927, Atlanta, Georgia.

[2] Agronomist, Florida Agricultural Experiment Station, Gainesville, Florida.

METHOD OF CULTURE

So far as observations at the Experiment Station go, it seems that Crotalaria may be handled pretty much like beggarweed. A bushel of hulled cleaned seed weighs between 60 and 70 pounds. Seventy-five to 80 thousand seed weigh a pound. Ten to 20 pounds of seed per acre planted any time from March to the latter part of June on well-prepared land and covered lightly has given satisfactory stands and excellent growth.

Broadcast and row seeding both give satisfactory results, the latter method of course requiring less seed to plant an acre. When planted in the spring, the plant starts blooming about 60 to 70 days after germination and seed begin maturing about 90 to 100 days after germination. Blooming is continous until frost, the plant being killed at 29° to 28° F.

No inoculation has been found necessary. This is supposedly due to the presence of a dwarfed native species generally over the state.

Seed may be harvested as they mature or left to fall on the ground and reseed the crop, its reseeding habit being exceptionally good. No accurate data are available as to the amount of seed the plant will produce. At the Florida Station in 1925 a yield of 177 pounds of hulled seed per acre was obtained and an excellent volunteer crop obtained on the land in 1926. Where grown for seed it seems best to plant in rows to induce branching, thereby giving more terminals, consequently more seed. Room between the rows facilitates hand gathering, which, so far, is the method of harvesting seed. It seems best, under some circumstances, to mow Crotalaria once during the year to prevent it from getting too coarse. Where this is desired, mowing should be done about the time, or soon after, blooming commences. A second crop will then come on rapidly, soon shade the ground, and produce enough seed to reseed the land. Where mowing has been done after seed are maturing, the second growth has not been entirely satisfactory. The crop should be mowed at least 8 to 10 inches high, as close mowing does not give a satisfactory second growth.

SOIL ADAPTABILITY

The crop has been tried out on numerous soil types of the state from Norfolk and Orangeburg sandy loams in northwestern Florida to raw saw-grass peat of the Everglades in south Florida and from the poorly drained flatwoods soils of the Portsmouth and Bladen series to the high, dry, rolling Norfolk sands of the ridge section of central Florida. On all of these kinds of soil, except the raw saw-grass peat, Crotalaria has made an excellent growth. On the Norfolk sands of the citrus section, where it is especially difficult to get satisfactory growth of cowpeas, beggarweed, and velvet beans, Crotalaria has out yielded all other legumes tried.

CLIMATIC RANGE

Crotalaria has made a good growth and matured seed in all parts of Florida. Seed sent to the Pedigreed Seed Company at Hartsville, South Carolina, produced satisfactory growth and matured seed. Seed sent to the Tennessee Station at Knoxville produced a satisfactory growth and matured seed. Further testing is probably necessary in the two last mentioned states, as well as in other parts of the south-east.

CHEMICAL COMPOSITION

Analysis by the chemistry department of the Florida Experiment Station shows that in total nitrogen Crotalaria compares favorably with cowpeas, velvet beans, and beggarweed grown at the same time on the same soil type and harvested at about the same stage of growth.

TABLE 1.—*Percentage of total nitrogen (dry basis) in crops grown at Gainesville, Fla.*

Crop	Tops	Roots
Beggarweed	1.64	1.07
Velvet beans	2.51	1.48
Cowpeas	2.29	1.65
Crotalaria	2.78	0.92

YIELD COMPARED WITH COMMON LEGUMES

Yields of Crotalaria on Norfolk sand at Gainesville for the past three years and on newly cleared Norfolk sand at Lake Alfred for the past two years have in each instance been higher than those of cowpeas, velvet beans, or beggarweed.

On Bladen fine sandy loam soil near Jacksonville, Crotalaria has out-yielded beggarweed and soybeans, no other legumes being tried.

TABLE 2.—*Yields of four leguminous crops in tons of air-dry material per acre at Gainesville, Florida.*

Crop	1924	1925	1926	3-year averages
Beggarweed	0.79	0.92	0.15	0.62
Velvet beans	0.98	0.82	0.76	0.85
Cowpeas	1.48	1.30	0.52	1.10
Crotalaria	2.59	1.90	4.18	2.89

TABLE 3.—*Yields of four leguminous crops in tons of air-dry material per acre at Lake Alfred, Florida.*

Crop	1925	1926	Average
Beggarweed	2.29	1.78	2.03
Velvet beans	1.27	1.53	1.40
Cowpeas	1.27	1.01	1.14
Crotalaria	4.63	2.76	3.69

CROTALARIA AS A SOIL BUILDER

Yields of corn and sweet potatoes following the growing and turning under the previous year of crops of Mexican clover (*Richardia scabra* St. Hil.), Crotalaria, velvet beans, cowpeas, and beggarweed have been used as a measure of the land-building power of Crotalaria for two years. A study of Tables 4 and 5 shows that Crotalaria has been superior to the non-legume Mexican clover when measured in yields of corn and sweet potatoes following the two turned under.

Corn yields one year were higher following velvet beans and cowpeas than they were following Crotalaria, but the next year yields were higher following Crotalaria than any other legume. An average for the two years shows velvet beans ranking first and Crotalaria second in point of corn yields following the turning under of the legumes.

TABLE 4.—*Corn yields in bushels per acre following non-legumes and legumes turned under.*

Year	Non-legume	Crotalaria	Velvet beans	Cowpeas	Beggarweed
1925	15.13	21.71	22.99	22.28	19.28
1926	8.40	17.65	16.66	12.90	11.75
Average	11.76	19.68	19.82	17.59	15.51

Sweet potato yields each year have been higher following Crotalaria than they have been following any of the other legumes.

TABLE 5.—*Sweet potato yields in bushels per acre following non-legumes and legumes turned under.*

Year	Non-legume	Crotalaria	Velvet beans	Cowpeas	Beggarweed
1925	37.50	78.00	54.50	61.00	55.00
1926	26.09	39.72	34.33	33.75	27.19
Average	31.79	58.86	44.41	47.37	41.09

INFLUENCE ON SOIL ORGANIC MATTER

A preliminary study by the Chemistry Department of the Florida Station on the humus and nitrogen content of the soil on which one crop each of Mexican clover, beggarweed, velvet beans, cowpeas, and Crotalaria had been grown and turned under would seem to indicate that Crotalaria has favorably influenced the humus and nitrogen content of the soil. This is found by a study of Table 6, which shows the percentage of humus and nitrogen in the soil samples to a depth of 6 inches.

TABLE 6.—*Humus and nitrogen determinations in potato-legume, corn-legume rotation plats.*

Treatment	Analysis of soil, 0 to 6 inches in depth			
	Humus	Humus per acre	Nitrogen	Nitrogen per acre
	%	*Pounds*	%	*Pounds*
Check (Mexican clover).	0.826	16,520	0.0231	462
Beggarweed	0.829	16,580	0.0232	464
Velvet beans	0.910	18,200	0.0236	472
Cowpeas	0.863	17,260	0.0244	488
Crotalaria	0.946	18,920	0.0257	514

ADVANTAGES AND DISADVANTAGES

The advantages of Crotalaria as a soil-building crop seem to be about as follows: It fills a long-felt need for a crop which grows on poor, thin, sandy land; seeds freely; reseeds well; smothers out undesirable crops; is so far practically free from serious insect and disease enemies; and when turned back to the soil adds plenty of vegetable matter rich in nitrogen.

The disadvantages of Crotalaria as a cover and land-building crop seem negligible. It sometimes happens that crops planted for cover and land-building purposes are cut for feed. This would hardly happen in the case of Crotalaria, since stock apparently care but little for the plant, either green or dry.

Further experimental work is being conducted with Crotalaria as a forage crop.

SPINNING QUALITIES OF SOME COTTONS GROWN IN THE SOUTH ATLANTIC STATES[1]

(Abstract)

H. H. WILLIS[2]

Keen competition in cotton manufacture is largely responsible for the increasing demand on the part of the manufacturer for better cotton, that is, for cotton of known spinning characteristics which may fit his particular needs. The ideal cotton, satisfactory both to cotton breeder and to manufacturer, should possess not only high productivity but also spinning quality.

What is meant by the term "spinning quality" and some of the factors which affect spinning quality of cotton will be discussed in this paper. Although cottons from various sections of the cotton belt have been tested, practically all of the data to be presented are based upon recent spinning tests of North Carolina and South Carolina cottons. The manufacturing tests were conducted at Clemson College, South Carolina, in cooperation with Clemson Agricultural College. Spinning tests have recently been undertaken by the Bureau of Agricultural Economics at College Station, Texas, in cooperation with the Agricultural and Mechanical College of Texas.

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[1] Resume of paper presented before the Agronomy Section of the Southern Agricultural Workers' Association, February 3, 1927, Atlanta, Georgia.

[2] Associate Marketing Economist, Bureau of Agricultural Economics, U. S. Department of Agriculture, Washington, D. C.

The term "high spinning quality" as applied to cotton implies three things, *viz.*, (1) that the yarn spun from the particular cotton possessed strength, uniformity, elasticity, and brightness; (2) that the cotton had a minimum amount of short fiber; and (3) that but few broken ends occurred while the yarn was being spun. Keeping these points in mind, some of the factors which influence spinning quality will now be considered.

The chief factors generally agreed upon as determining spinning quality in cotton fiber may be divided into two classes. First, those discernible by the cotton classer or manufacturer, such as grade, length, and character, the term "character" including the qualities of strength, body, and uniformity. Second, those factors that may be detected only by the use of the microscope, such as fineness of diameter, convolutions or natural twist, and other physical characteristics.

The studies of the factors influencing spinning quality may be classified under two closely correlated heads, *viz.*, (1) manufacturing tests and (2) laboratory investigations. The factors are studied through the medium of manufacturing or spinning tests and the conclusions drawn from such studies will be taken up first. The first factor, that of grade, is a composite quality, determined largely by color, foreign matter, and preparation or ginning. Based on test data, the findings in respect to the relation between grade and spinning and finishing qulaities are as follows: If the cotton is either gray or blue stained, its bleaching qualities are reduced, in case the cotton is yellow tinged or stained, its finishing qualities are not noticeably affected; that these colors are generally less desirable for gray goods than is white cotton; that large trash is removed as waste, thus reducing the net weight of spinnable cotton, whereas some of the small or pin trash is spun into the yarn, thus reducing the quality of the yarn by detracting from its appearance; that gin damage to cotton not only increases the amount of short fiber waste but also makes the yarn irregular both in strength and in appearance; and that excessive short fiber lessens yarn strength and thus lowers its quality.

These spinning tests indicate that short staples are suitable only for coarse yarns, while the longer staples are required for the manufacture of fine yarns.

Test data show that uniformity of strength and size is most essential to quality; that, generally speaking, mixed or mongrelized cotton lacks uniformity, has a high percentage of short fiber waste, produces irregular yarn, and has a high end breakage in spinning; that, in general, known varieties of cotton are uniform in fiber strength and length, possess good spinning quality, and produce yarn of high breaking strength.

The foregoing conclusions have been based largely upon manufacturing tests. The laboratory investigations, which thus far have had to do mainly with the factors of fiber length and strength as related to yarn strength will now be considered.

A laboratory method by which the breaking strength of yarn can be estimated by the use of a small sample of raw cotton, even so small as the product of one plant, has been developed in the laboratory of the Bureau of Agricultural Economics. As a first step in this development, a device[3] was invented whereby the strength of cotton fiber was determined by breaking several thousand fibers in bulk simultaneously. As a second step, the writer tested eight lots of cotton representing seven varieties grown in South Carolina[4] during 1925, not only by the foregoing bulk method but also by spinning tests. As a third step, the data on fiber length and strength, as obtained by laboratory methods, were correlated with data on yarn strength as obtained by manufacturing tests, and a formula was derived for estimating the breaking strength of 28s yarn.[5]

This estimating formula has since been applied to some 43 lots of cotton representing varieties grown in North Carolina, South Carolina, and Texas, ranging in staple length from 13/16 to 1¼ inches. Of these 43 lots tested by this method, only 13 showed a variation of more than 6% between the actual and estimated strengths of 28s yarns. The foregoing preliminary data indicate that fiber length accounts for 61% of the yarn strength and that fiber strength accounts for 11% of the yarn strength.

Data on the actual and estimated strengths of yarns spun from nine lots of North Carolina cotton are shown in detail in Table 1.

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[3] CHANDLER, E. E. A new method for determining the strength of cotton. U. S. D. A. Preliminary Report.

[4] WILLIS, H. H. Spinning tests of leading varieties of South Carolina cottons, crop of 1925, U. S D. A. Preliminary Report.

[5] This formula was derived by Mr. E. M. Daggit and Mr. H. B. Richardson of the Bureau of Agricultural Economics.

TABLE 1.—*Correlation of length of staple, strength of fiber, and strength of 28s yarn.*

Variety and place grown in North Carolina	Length of staple, inches	Strength of raw cotton per square inch of cellulose, pounds	Strength of 28s yarn per skein of 120 yards		Difference between actual and estimated strength of 28s yarn	
			Actual in pounds	Estimated in pounds	*Pounds*	%
Cleveland (Oxford).....	0.875	58,400	65.7	63.8	+1.9	2.89
Trice (Oxford)..	0.875	55,900	71.8	62.8	+9.0	12.53
Sugar Loaf (Oxford).....	0.875	57,800	71.9	63.6	+8.3	11.54
Mexican (Speed)	1.078	50,500	72.1	74.5	—2.4	3.33
Mexican (Oxford)	1.063	57,700	72.9	76.3	—3.4	4.66
Mexican (Kingsboro)..	1.063	58,100	73.4	76.4	—3.0	4.09
Acala (Oxford)..	1.125	59,400	75.5	81.2	—5.7	7.55
Mexican (Raleigh)....	1.094	55,900	76.6	77.7	—1.1	1.44
Acala (Fayetteville).	1.141	58,600	82.4	81.9	+0.5	0.61

This method of estimating yarn strength has not yet been fully developed and will no doubt be subject to slight change as more extensive tests are conducted and as various factors influencing yarn strength, as yet undetermined, are measured with some degree of accuracy. The results already obtained, however, indicate its possibilities. The specialists of the cotton testing project consider this one of the best pieces of research in raw cotton, and believe that it will prove of special value in the study of the factors influencing spinning quality in cotton.

BIBLIOGRAPHICAL CONTRIBUTIONS ON SOILS

The U. S. Department of Agriculture Library now has available for distribution three additional numbers in its series of "Bibliographical Contributions" which will be of interest to agronomists. These were prepared at the request of the Organizing Committee of the First International Congress of Soil Science and may now be had free of charge upon request to the Librarian. The "Contributions" are in mimeographed form bound between paper covers.

Bibliographical Contribution No. 13 is "A Classified List of Soil Publications of the United States and Canada." An attempt has been made to bring together in this list all American publications dealing in a tehnical way with soils in general, soil classification and nomenclature, soil geography, soil chemistry, soil physics and mechanics, soil biology and biochemistry, soil ecology, soil fertility, soil management, and fertilizers. A classified index completes the publication.

Supplementing the general list noted above are Contributions Nos. 14 and 15 dealing with soil publications of the United States Department of Agriculture and the state experiment stations, respectively. In Contribution No. 14 is listed the soil publications of the Department from 1844 to 1926. In Contribution No. 15 is listed the publications on soils issued by the state experiment stations through 1926. These last two lists have been prepared separately for convenience of reference, all of the material contained in them being included in the general list in Contribution No. 13. (J. D. L.)

AGRONOMIC AFFAIRS

ANNUAL MEETING OF THE SOCIETY

The twentieth annual meeting of the American Society of Agronomy will be held in the Congress Hotel, Chicago, on November 17 and 18. While the program has not been fully arranged, the following symposia topics will be discussed:

"The Soil Solution," Dr. G. J. Bouyoucos, *Leader.*

"Cotton," Director M. J. Funchess, *Leader.*

"Field Technic in Soils and Crops Experiments," Dr. E. L. Worthen, *Leader.*

"Extension Work," Prof. G. E. Farrell, *Leader.*

"Water Relations," Dr. H. L. Shantz, *Leader.*

MEETING OF THE NEW ENGLAND SECTION OF THE SOCIETY

The fourteenth annual meeting of the New England Section of the American Society of Agronomy will be held at Boston, December 2 and 3. Symposia on "Land Utilization Programs" and "Fertilizer Requirements of Specific Crops" will be held.

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THE REGISTERED VARIETIES OF AMERICAN WHEAT: THEIR CLASS, ORIGIN, AND ACREAGE[1]

J. ALLEN CLARK[2]

ORIGIN OF WHEAT VARIETIES

The purpose of this paper is to summarize the data on the number of recognized or registered wheat varieties, and their commercial acreage, with respect to class and origin.

The varieties may be separated as to origin into three groups, *viz.*, (1) by introduction, (2) by selection, and (3) by hybridization. Introduction from foreign countries was the first or early method of obtaining varieties. Selection followed as a method of improvement of introduced and domestic sorts. Finally, hybridization furnished a more scientific method of originating new and improved varieties.

These methods have been used by both public and private workers. The older varieties were introduced, selected, or bred by farmers. With the organization of the United States Department of Agriculture and the state agricultural experiment stations, many varieties of wheat and other cereals were introduced, and agronomists at publicly supported federal, state, or provincial experiment stations in the United States and Canada began improving old varieties and originating new varieties by selection and hybridization.

VARIETAL SURVEY AND THE AGRICULTURAL CENSUS FOR 1924

The first estimates of the commercial acreage of all wheat varieties grown commerically in the United States were made in 1919 and were based upon replies to varietal questionnaires from crop correspondents and upon preliminary acreages reported by the Fourteenth United States Census. These estimates were published in U. S. Department of Agriculture Bulletin No. 1074.[3] A second varietal survey was made in a similar manner in 1924. A special federal agricultural census was taken in 1925 and covered the 1924 crop. The reports of this census by states recently have been published and the results of the varietal survey have been prepared for publication.

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[1] Paper read at the meeting of the Western Section of the American Society of Agronomy held at Moro, Oregon, June 27 to 29, 1927. Received for publication July 8, 1927.

[2] Agronomist in Charge, Western Wheat Investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture.

REGISTRATION OF WHEAT VARIETIES

The recognized varieties of wheat have been registered by the American Society of Agronomy in cooperation with the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.[4] New and improved varieties are being registered on the basis of merit as determined from experiments at federal or state stations.[5] Registration numbers have been assigned to 252 varieties, and registration certificates are issued for the new and improved varieties. In Table 1 is presented an alphabetical list of the registered varieties, their registration numbers, commercial class, origin, and estimated acreage in 1924. Not all registered wheat varieties are commercially grown, and there are a few commercial varieties which have not been registered. Some of the old standard varieties which were commercial in 1919 had gone out of cultivation by 1924 and several of the new improved varieties had become established.

CLASSES

Most of the varieties, when marketed, are graded in one of the five commercial classes,*viz.* (1) Hard Red Spring, (2) Durum, (3) Hard Red Winter, (4) Soft Red Winter, and (5) White. The term wheat in the "Official Standards" does not include varieties of emmer, spelt, einkorn, and Polish and poulard wheats which are classed as "cereal grains." There are 12 registered varieties of these cereal grains of which Vernal (emmer) and Alaska (poulard wheat) are commercially grown.

HARD RED SPRING WHEATS

The hard red spring wheats occupied 22.4 % of the total wheat acreage of the United States in 1924. There are 39 registered varieties in this class of which 20 were reported commercially grown in 1924. Marquis is the leading variety of the class and the second most widely grown variety in the United States with an estimated acreage of 9,605,870 acres. The hard red spring varieties of next importance, ranked in the order of their 1924 acreage, are Kota, Preston, Ruby, Red Fife, Haynes Bluestem, and Power.

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[3] CLARK, J. A., MARTIN, J. H., and BALL, C. R. Classification of American wheat varieties. U. S. D. A. Bul. 1074. 1922.

[4] CLARK, J. A., LOVE, H. H., and GAINES, E. F. Registration of standard wheat varieties. Jour. Amer. Soc. Agron., 18:920–922. 1926.

[5] CLARK, J. A., LOVE, H. H., and PARKER, J. H. Registration of improved wheat varieties. Jour. Amer. Soc. Agron., 18:922–935. 1926.

DURUM WHEATS

The durum wheats occupied 8.2% of the total wheat acreage of the United States in 1924. The identity or varietal name of much of the durum wheat grown is not known. For this reason nearly 75% of the durum acreage was reported merely as durum. This is practically all Arnautka and Kubanka, and these two varieties are here estimated to be in the proportion of 70 to 30%, respectively. While Kubanka is the best known durum variety, Arnautka always has been more widely grown. There are 15 registered durum varieties of which 10 were commercial in 1924. The principal varieties rank, in order of their estimated acreage, as follows: Arnautka, Kubanka, Pentad, Monad, Acme, Kahla, Mindum, and Peliss.

HARD RED WINTER WHEATS

Hard red winter wheats occupied 41.4% of the total wheat acreage in 1924. There are 26 registered varieties in this class. Seventeen varieties were reported commercially grown in 1924. The leading variety is Turkey, with its many synonyms, including Kharkof. Turkey is not only the leading variety in its class, but ranks first among all varieties grown in the United States, with an estimated acreage of 14,332,147 acres. Of this, 15%, or 2,149,822 acres, is here estimated to be Kharkof. Kanred, with 4,314,962 acres in 1924, ranked second to Turkey in acreage, followed by Blackhull, Michikof, Minturki, Montana No.36, Nebraska No. 60, and Ilred.

SOFT RED WINTER WHEATS

The soft red winter wheats occupied 22.1% of the total wheat acreage in the United States in 1924. There are 85 registered varieties of soft red winter wheat, including 5 red-kerneled club varieties. There were 58 varieties of this class reported commercially grown in 1924, including 2 of the red-kerneled club wheats. Three varieties each occupied over 1,000,000 acres, and 20 varieties over 100,000 acres each. These 20 varieties ranked in order of their commercial importance as follows: Fulcaster, Fultz, Poole, Mediterranean, Trumbull, Leap, Red Wave, Harvest Queen, Red May, Red Rock, Currell, Nittany (Pa. No. 44), Ruby, Nigger, Jones Fife, Purplestraw, Gladden, Goens, Triplet, and Flint.

WHITE WHEATS

The white wheats occupied but 5.9% of the total wheat acreage in the United States in 1924. There are 75 registered varieties of

TABLE 1.—*Alphabetical list of the registered wheat varieties showing registration number, commercial class, method and agency of origin, and estimated acreage for the United States in 1924.*

Variety	Reg. No.	Commercial class	Method and agency of origin, and acreage					
			Introduction		Selection		Hybridization	
			Public	Private	Public	Private	Public	Private
Acme	211	D			65,457			
Akrona	246	D			0			
Alaska (poulard)	206			408				
Allen	76	W		5,114[a]				
Alstroum (spelt)	226			0				
Alton	55	H.R.W.	532					
Arcadian	72	W						0
Ariette	179	S.R.W.		0				
Arnautka	213	D		2,180,180[b]				
Ashkof	235	H.R.W.			0			
Ashland	49	S.R.W.			2,415			
Baart	123	W	485,159					
Bacska	151	H.R.W.			1,259			
Bearded (spelt)	228			0				
Bearded Winter Fife	182	W						0
Beloglina	150	H.R.W.	34					
Big Club (club)	192	W		24,581[c]				
Big Frame	33	S.R.W.				0[a]		
Blackhull	142	H.R.W.				1,519,992		
Black Winter (emmer)	224		0					
Bluechaff (club)	200	W				2,385[c]		
Bobs	22	W	0					

Buffum No. 17	34	S.R.W.				0		
Buford	217	D			0			
Bunyip	15	W		29,508[d]				
Canadian Red	165	W		0			0	
Ceres	241	H.R.S.						
Challenge	6	W				0		
Champlain	135	H.R.S.						0
China	95	S.R.W.		57,671				
Chul	161	H.R.S.	1,778					
Clackamus (poulard)	205			0[a]				
Climax	67	S.R.W.				6,265		
Colorado No. 50	11	W			0			
Converse	138	H.R.S.		0				
Coppei (club)	202	S.R.W.				29,460[c]		
Cox	173	S.R.W.		0[a]				
Currell	90	S.R.W.				259,290		
Dakota	112	H.R.S.			0			
Dale (club)	201	S.R.W.				0		
Dart	18	W		0				
Dawson	69	W				61,668		
Defiance	13	W						36,224
Democrat	116	W		597[a]				
Diamond Grit	133	S.R.W.						0
Dicklow	21	W				115,947		
Diehl-Mediterranean	169	S.R.W.						59,095
Dixon	160	H.R.S.				0		
Early Defiance	10	W				1,687		
Early Red Fife	63	H.R.S.			0			

TABLE 1.—*Continued.*

Variety	Reg. No.	Commercial class	Method and agency of origin, and acreage					
			Introduction		Selection		Hybridization	
			Public	Private	Public	Private	Public	Private
Eaton	7	W		6,945				
Emerald	163	W				1,610		
Erivan	137	H.R.S.	0					
Federation	77	W	32,696					
Fleming	83	S.R.W.		80				
Flint	47	S.R.W.				100,377		
Foisy	78	W				11,155		
Forward	41	S.R.W.			4,987			
Fretes	159	H.S.R.	—					
Fulcaster	131	S.R.W.						1,816,534
Fulhio	231	S.R.W.			82,201			
Fultz	48	S.R.W.				1,786,971		
Fultzo-Mediterranean	51	S.R.W.						86,878[a]
Galgalos	113	W	14,842					
Genesee Giant	164	W						1,540
Ghirka	64	S	0					
Gipsy	127	S.R.W.				82,223[a]		
Gladden	126	S.R.W.			100,843			
Gluten	156	S.R.W.			0			
Glyndon	60	H.R.S.			430			
Goens	172	S.R.W.						100,688
Goldcoin	74	W				670,852		
Gold Drop	80	S.R.W.		1,104				
Golden Ball	220	D	0					
Golden Cross	134	S.R.W.						0
Grandprize	115	S.R.W.						13,389[a]
Greeson	4	W				11,173		
Gypsum	19	W					1,520	
Hard Federation	79	W	12,793[c]					

Harvest Queen	39	S.R.W.				403,495		
Haynes Bluestem	111	H.R.S.				133,031		
Homer	81	S.R.W.				0[a]		
Honor	70	W			4,718			
Hope	240	H.R.S.						0
Humpback	188	H.R.S.				956		
Huron	175	H.R.S.					0	
Hussar	140	H.R.W.			0			
Huston	54	H.R.S.		25,081				
Hybrid 60 (club)	194	W					0	
Hybrid 63 (club)	195	W						13,969[c]
Hybrid 108 (club)	196	S.R.W.					0	
Hybrid 123 (club)	197	S.R.W.					64,252[c]	
Hybrid 128 (club)	190	W					516,502[c]	
Hybrid 143 (club)	193	W					16,019[c]	
Illini Chief	98	S.R.W.				2,940		
Ilred	232	H.R.W.			9,205			
Imperial Amber	171	S.R.W.				400		
Indian	107	W				957		
Iobred	236	H.R.W.			557			
Iowa No. 404	144	H.R.W.			4,942			
Iowa No. 1946	145	H.R.W.			0			
Java	136	H.R.S.		9,106				
Jenkin (club)	198	W				139,041[c]		
John Brown	75	W	0[b]					

TABLE 1.—*Continued.*

Variety	Reg. No.	Commercial class	Method and agency of origin, and acreage					
			Introduction		Selection		Hybridization	
			Public	Private	Public	Private	Public	Private
Jones Fife	110	S.R.W.						209,222
Jumbuck	106	W	0[b]					
Kahla	221	D	45,579					
Kanred	149	H.R.W.			4,314,962			
Karmont	244	H.R.W.			1,272			
Khapli (emmer)	222		0					
Kinney	52	H.R.S.		8,353				
Kitchener	66	H.R.S.				5,451		
Kofod	68	W				5,713		
Kota	153	H.R.S.			471,313			
Kubanka	215	D	1,403,519[f]					
Kubanka No. 8	216	D			0			
Ladoga	177	H.R.S.		2,593				
Laramie	178	H.R.S.			0			
Leap	35	S.R.W.				511,774		
Link	162	W				0		
Little Club (club)	191	W		27,468[c]				
Lofthouse	32	S.R.W.		635[a]				
Longberry No. 1	166	W						0
Lynn	26	W				0		
Mammoth Amber	119	W						0
Mammoth Red	132	S.R.W.				6,412		
Marouani	218	D	4,691					
Marquillo	237	H.R.S.					0	
Marquis	57	H.R.S.					9,605,870	
Martin	2	W				6,373		
Mayview (club I)	204	S.R.W.				0		
Mealy	09	S.R.W.				7,833		

Mediterranean	180	S.R.W.		599,967				
Mexican Bluestem	17	W		0				
Michikof	233	H.R.W.			52,550			
Minard	238	H.R.W.			0			
Mindum	214	D			11,953			
Minhardi	31	S.R.W.					0	
Minturki	139	H.R.W.					36,970	
Monad	212	D	84,203					
Montana No. 36	146	H.R.W.			22,852			
Mosida	247	H.R.W.					0	
Nebraska No. 28	125	S.R.W.					0	
Nebraska No. 60	147	H.R.W.			13,552			
New Amber Longberry	167	W						
Newturk	245	H.R.W.					0	0
New Zealand	28	W		4,630				
Nigger	157	S.R.W.				197,380		
Nodak	242	D			—			
Norka	176	H.R.S.			0			
Oakley	45	S.R.W.				1,763[a]		
Oatka Chief	118	W						0
Odessa	85	S.R.W.	22,395					
Onas	252	W	0[c]					
Ontario Wonder	36	S.R.W.				0[a]		
Pacific Bluestem	16	W		371,434				
Palisade	120	W				2,236		
Peliss	210	D	5,055					

TABLE 1.—*Continued.*

Variety	Reg. No.	Commercial class	Method and agency of origin, and acreage: Introduction Public	Introduction Private	Selection Public	Selection Private	Hybridization Public	Hybridization Private
Penquite	189	S.R.W.				13,764		
Pentad	209	D	341,147					
Pesterboden	141	H.R.W.	0					
Peterson	84	S.R.W.				0		
Pilcraw	29	W				0		
Pioneer	154	S					0	
Poole	92	S.R.W.				1,050,023[a]		
Portage	93	S.R.W.			57,320			
Power	59	H.R.S.			53,014			
Prelude	187	H.R.S.					7,371	
Preston	152	H.R.S.				39	2,176	
Pride of Genesee	185	S.R.W.						0
Progress	234	H.R.S.			397			
Prohibition	3	W	15,522					
Propo	121	W				8,983		
Prosperity	40	S.R.W.						1,499
Purplestraw	53	S.R.W.[h]		116,340[a]				
Quality	23	W						11,876
Read	183	W						0
Red Bobs	56	H.R.S.				14,586		
Redchaff (club)	199	W				3,264[c]		
Red Chief	101	S.R.W.						69
Red Clawson	99	S.R.W.						21,925
Red Fife	58	H.R.S.		175,008				
Red May	97	S.R.W.				399,915		
Red Rock	181	S.R.W.			342,671			
Red Russian	43	S.R.W.		52,287				
Red Wave	82	S.R.W.						435,198
Red Winter (spelt)	227		9					

Regal	250	H.R.W.		0			
Regenerated Defiance	27	W		209			
Reliance	243	H.R.S.				0	
Resaca	103	S.R.W.[h]	0[a]				
Rice	30	S.R.W.	54,560[a]				
Ridit	248	H.R.W.				—	
Rink	14	W	19,105[a]				
Rochester	100	S.R.W.			123[a]		
Ruby	65	H.R.S.				329,958	
Ruddy	86	S.R.W.				0	
Rudy	155	S.R.W.			250,801		
Rupert	87	S.R.W.			13,121		
Rural New Yorker No. 6	88	S.R.W.					5,777
Rural New Yorker No. 57	184	S.R.W.					0
Russian	170	S.R.W.	18,808[a]				
Russian Red	94	S.R.W.	50,474				
Rysting	61	H.R.S.			0		
Satisfaction	9	W			0[a]		
Schlanstedt	102	H.R.S.	0				
Schonacher	71	S.R.W.	0[a]				
Seneca Chief	117	W			0		
Sevier	168	W			2,226		
Shepperd	253	S.R.W.		0			
Sherman	249	H.R.W.		0			
Sibley	130	S.R.W.					0
Silvercoin	105	W			1,389		
Silversheaf	158	S.R.W.					0

TABLE 1.—*Continued.*

Variety	Reg. No.	Commercial class	Method and agency of origin, and acreage					
			Introduction		Selection		Hybridization	
			Public	Private	Public	Private	Public	Private
Sol	44	S.R.W.		753				
Sonora	114	W		88,017				
Squarehead	42	S.R.W.		0				
Squareheads Master	89	S.R.W.		0				
Stanley	104	H.R.S.					0	
Surprise	20	W						16,556
Talimka	124	W	0					
Titanic	207			0				
Touse	12	W	8,560					
Treadwell	122	W						0
Triplet	108	S.R.W.					100,627	
Trumbull	50	S.R.W.			593,427			
Turkey	143	H.R.W.	(2,149,822)^g		12,182,325^g			
Valley	128	S.R.W.				4,316		
Velvet Don	219	D	0					
Vernal (emmer)	223			0				
Virginia	186	S.R.W.					0	
Walker	38	S.R.W.		1,633^a				
Webster	239	H.R.S.	0					
Wellman	62	H.R.S.				0		
Wheedling	96	S.R.W.				3,372		
White Federation	25	W	1,311^e					
White Fife	24	W				0		
White Odessa	251	W						
White Polish	229			0				
White Spring (spelt)	225			0				
White Winter	5	W		29,593				

White Wonder	8	W				0[a]		
Wilbur	203	W				0		
Windsor	73	W				0[a]		
Winter Alaska	208		0					
Winter Bluestem	1	W					0	
Winter Chief	91	S.R.W.				0[a]		
Wisconsin Ped. No. 2	148	H.R.W.			3,123			
Wisconsin Ped. No. 40	129	S.R.W.			0			
Wyandotte	46	S.R.W.			0			
Yaroslav	174	H.R.W.	0					
Zimmerman	37	S.R.W.				196		
Total (252)								
Number of varieties			34	49	45	66	27	31
Number of acres (48,744,218)			4,629,638	16,144,358	6,215,629	7,852,889	11,085,234	2,816,470
Percentage of varieties			13.5	19.4	17.9	26.2	10.7	12.3
Percentage of acreage			9.5	33.1	12.8	16.1	22.7	5.8

[a] Origin undetermined, method indicated being most probable.

[b] Includes 23,075 acres reported as Arnautka and 70%, or 3,081,578 acres, of that reported only as durum.

[c] Corrected by including its relative proportion of the 10 commercial club varieties, of 162,079 acres reported only as club.

[d] A foreign introduction of hybrid origin.

[e] A foreign introduction developed by selection.

[f] Includes 479,046 acres reported as Kubanka and 30%, or 924,473 acres, of that reported only as durum.

[g] The 14,332,147 acres of Turkey and its synonyms is here divided, estimating 85% as Turkey and 15%, or 2,149,822 acres, as Kharkof, an introduction by the United States Department of Agriculture.

[h] Red wheats with spring habit of growth but which always have been grown from fall seeding in the South are classed as soft red winter.

white wheat, including 10 white-kerneled club varieties. There were 46 varieties of white wheat reported commercially grown in 1924, including 8 of the white-kerneled club wheats. Goldcoin, and its synonyms, including Fortyfold, was the most widely grown white wheat with an estimated acreage of 670,852 acres. The principal white varieties ranked in the following order: Goldcoin, Baart, Hybrid 128, Pacific Bluestem, Dicklow, Jenkin, Sonora, Dawson, Defiance, Federation, White Winter, and Bunyip.

ORIGIN

It is of interest to classify the recognized or registered varieties by method of origin. In Table 1, the varieties are separated as to origin from introduction, selection or hybridization, and whether by public or private agencies. Canadian varieties are not classified as introductions as they are of American origin. Varieties from all other countries are listed as introductions but the fact is noted if they are known to have been originated by selection or hybridization. The origin of several varieties is undetermined, but for these the most probable origin is indicated.

BY INTRODUCTION

Eighty-three of the 252 registered varieties are indicated to be foreign introductions. This is practically a third of the varieties, and their combined acreage makes up 42.6% of that of all the registered varieties. Of the 83 introduced varieties 49 were introduced by private individuals and 34 by public institutions.

The principal varieties introduced by private individuals are Turkey, a hard red winter wheat, and Arnautka, a durum wheat. The total acreage of these two varieties is more than 14,000,000 acres. Other varieties privately introduced, which are still important commercially, are Mediterranean, Pacific Bluestem, Red Fife, Purplestraw, Sonora, and China.

The more important varieties introduced by public institutions are Kharkof, a hard red winter wheat, and Kubanka, a durum wheat. The estimated acreage of these varieties in 1924 totals more than three and a half million acres. Other important commercial varieties introduced by public institutions are Baart, Pentad, Monad, Kahla, Federation, Odessa, Galgalos, Prohibition, and Hard Federation.

The acreage of the privately introduced varieties amounts to 33.1% of that of all registered varieties as compared with 9.5% of the acreage for varieties introduced by public institutions.

BY SELECTION

Of the 252 registered varieties, 111 are recorded as being developed by selection. This is 44.1% of all the varieties. Of the 111 selections, 66 were made by private individuals and 45 by scientific workers in public institutions.

The principal varieties selected by private individuals are Fultz, Blackhull, and Poole, each of which is grown on more than 1,000,000 acres. Additional important varieties in order of their rank are Leap, Harvest Queen, Red May, Currell, Rudy, Jenkin (club), Haynes Bluestem, Dicklow, Flint, Gipsy, Dawson, and Coppei.

The principal varieties selected by scientific investigators at public institutions are Kanred, Trumbull, Kota, and Red Rock. Other important varieties in order of their commercial acreage are Gladden, Fulhio, Portage, Power, Michikof, Acme, Montana No. 36, Nebraska No. 60, Mindum, Iobred, Iowa No. 404, Honor, Wisconsin Ped. No. 2, and Karmont.

In all, 28.9% of the acreage is of varieties developed through selection. Of this, 16.1% are of those made by private individuals and 12.8% of those by public workers.

BY HYBRIDIZATION

Fifty-eight of the 252 registered varieties are recorded as having been originated through hybridization. Thirty-one of these have been made by private workers and 27 by public workers. The principal varieties originated through hybridization by private breeders are Fulcaster, Red Wave, Jones Fife, and Goens. Other important varieties in order of their estimated acreage are Fultzo-Mediterranean, Diehl-Mediterranean, Defiance, Red Clawson, Surprise, Grandprize, and Quality.

The principal varieties originated by hybridization by scientific workers at public institutions in the United States and Canada are Marquis, Hybrid 128, Preston, Ruby, Triplet, Hybrid 123, Minturki, Hybrid 143, Hybrid 63, and Gypsum.

Of the total acreage of all varieties 28.5% are of those developed through hybridization. Of this, 22.7% are of varieties developed by public workers and 5.8% are of varieties developed by private individuals.

DEVELOPED BY PUBLIC AND PRIVATE AGENCIES

Of the 252 varieties, 146 have been developed or introduced by private individuals and 106 by public agencies. The commercial acreage of these is 26,813,717, or 55%, for private individuals as compared with 21,930,501 acres, or 45%, by scientific workers at public institutions.

PRODUCTION AND STANDARDIZATION OF IMPROVED VARIETIES

During the past 20 years at least 50 improved varieties, developed by public or private agencies, have become important commercially. These were grown on over 20,000,000 acres in 1924. It is conservative to estimate that these improved varieties yield, on the average, 2 bushels per acre more than the varieties they replaced. Thus 40,000,000 bushels may have been added to the annual wheat production of the United States by the use of improved varieties, with little or no additional expense to the growers.

Nearly two-thirds of the acreage has continued to be used for the growing of old standard varieties. Thus, there is a big field for further improvement. Most of the new varieties are now being developed by trained workers at public institutions, whereas in the past more of the varieties were developed by private individuals on farms. For further improvement much more careful and scientific work is necessary than was formerly the case. Few private breeders can now afford to entail the necessary expense. Their rights and efforts, however, must continue to be recognized and appreciated, and their productions should be as carefully tested and as willingly distributed as any others. Federal and state station and extension workers must cooperate with each other and with private breeders, commercial seedsmen, farmers, and the grain trade for continued and greater successes in the production and standardization of improved varieties.

AN IMPROVED METHOD OF PRODUCING F_1 HYBRID SEEDS OF WHEAT AND BARLEY[1]

C. E. ROSENQUIST[2]

In hybridizing wheat it is often advisable to secure as many F_1 kernels as possible. Especially is this true if, in the first generation, hybrid vigor is to be studied.

A method of crossing wheat and barley which results in a comparatively large number of crossed kernels per spike has been used at the Illinois Station with good success. This method has been designated as the "approach method" and is a variation of the method explained by Jelinek[3] in 1918.

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[1] Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois Agricultural Experiment Station, Urbana, Illinois. Published with the approval of the Director. Received for publication August 10, 1927.

[2] Assistant Professor of Agricultural Botany, University of Nebraska, Lincoln, Nebr.

[3] JELINEK, J. Beitrag Zur Technik der Weizenbastardierung. Zeitschr. für Pflanzenzücht., 6:55-57. 1918.

The "approach method" is especially adapted to greenhouse conditions, though it can be used in the field as well. To facilitate moving and handling, the plants were grown in gallon pots in the greenhouse. On the spike to be used as the female parent all of the outer glumes, lemmas, and stamens were removed. Then the middle rows of flowers were pulled off and the paleas of the remaining flowers cut off just above the stigmas in order to facilitate pollination. The same technic was followed with the male spike, excepting, of course, the removal of the stamens. Both spikes were well matured and the male spike about to shed pollen. Then the two spikes were fastened together with "O. K." paper clips, the male spike against and slightly higher than the female, and both covered with a paper bag. In order to give the spikes the correct relative position either culm can be bent over without any noticeable injurious effect. To facilitate

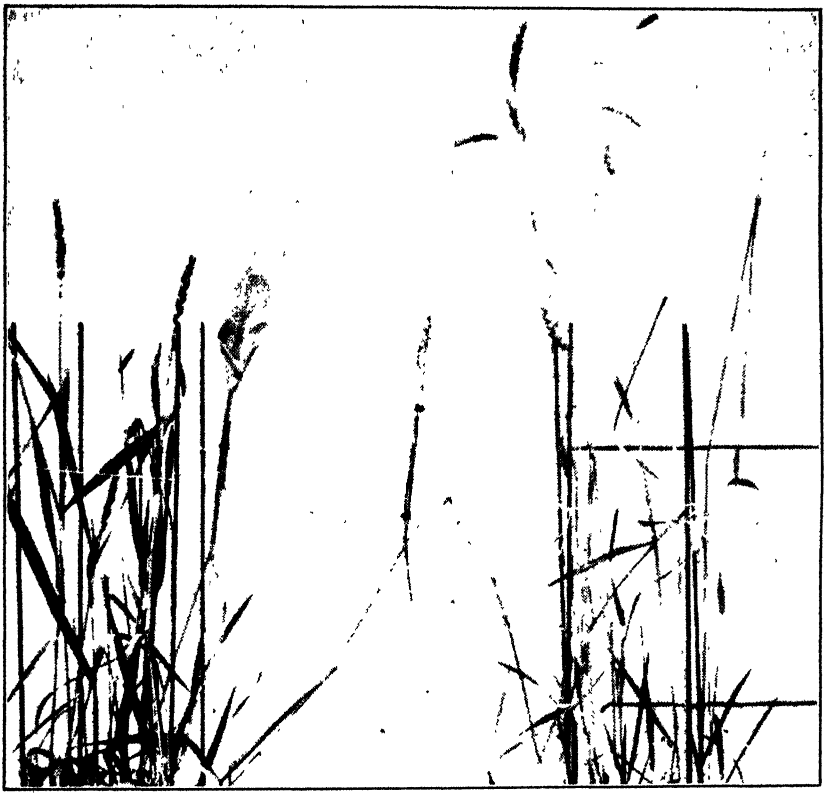

FIG. 1.—Showing the method of fastening the spikes together and the bending of the culms.

pollination the spikes should be shaken slightly three or four times after performing the operation. Fig. 1 shows the method of fastening the spikes together as well as the bending of the culms.

A total of 55 trials were made in the greenhouse in 1927, resulting in 577 hybrid kernels. This is an average of about 10.9 kernels per trial. Of these 55 attempts 5 resulted in no hybrid kernels whatever. The number of crossed kernels per spike ranged from 1 to 27. In a few instances one male spike was used to pollinate two and even three female spikes with good results. Two good "sets" of kernels are shown in Fig. 2.

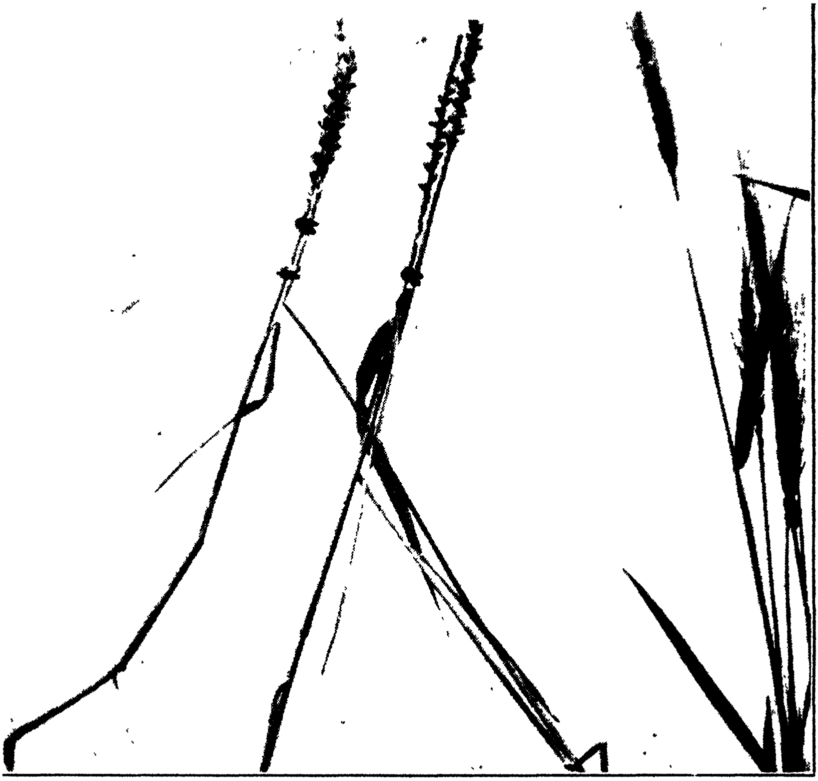

FIG. 2.—A good "set" of seed by the "approach method."

This method with barley has been used with fair success and with oats with poor success, since the spikelets of a panicle are too widely spread apart for good pollination

The "approach method" has been adapted to field work with some success. A culm was cut off just above the ground and placed beside the female plant in a small bottle of water. Where the plants to be crossed are grown side by side this is not necessary. The same technic was used as in the greenhouse. Caution must be taken, however, to prevent accidental pollination by pollen from neighboring plants.

Of 23 trials in the field a total of 330 kernels was obtained which is an average of about 14.3 kernels per spike. In 20 of these trials the male culms were kept in small bottles of water.

This method will be tested further both in the field and in the greenhouse. It should be of considerable value where comparatively large numbers of F_1 hybrid kernels are desired.

INTERVARIETAL COMPETITION AMONG SMALL GRAINS[1]

G. H. STRINGFIELD[2]

Competition is well recognized as a factor in determining which plants shall survive in nature. Competition among plants differing markedly in vigor, time and manner of growth, and other adaptive factors may exert a degree of influence, however, wholly different from that occurring in variety tests among similar varieties of cereals.

As part of their studies in competition, Keisselbach (2)[3], Hayes and Arny (1),and Stadler (4) have shown, under conditions obtaining at Nebraska, Minnesota, and Missouri, respectively, that yields of the small grains may be considerably influenced by adjacent rows of other varieties.

The Committee on Standardization of Field Experiments of the American Society of Agronomy (5) gives the following recommendation: "When varieties are planted adjacent to each other, without the intervention of alleys, certain ones may affect others adversely. When plats are flanked or surrounded by alleys it is known that the yields are increased and that all varieties are not influenced alike. To obviate these difficulties it is recommended that two drill rows from either side of each plat in the case of small grain and an equivalent width in the case of broadcasted grain or forage crops, and one row from either side of each plat in intertilled crops, be either removed before harvest or left unharvested."

[1] Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Published with the approval of the Director. Received for publication July 29, 1927.

[2] Assistant Agronomist. The writer is indebted to Mr. L. E. Thatcher for many valuable suggestions in the preparation of this paper.

[3] Reference by number is to "Literature Cited," p. 983.

Love (3) says, "In certain experiments conducted at Ithaca, New York, where the rows run from north to south and data are available it is shown that there is little competition between varieties; in fact, there is so little between the ordinary varieties usually tested in any one locality that no correction would be necessary. Perhaps for other conditions the results would be different."

The present work is concerned with competition as a possible disturbing factor in yield trials. The plantings known as the cereal nurseries would probably suffer most from such a condition and it is in them that the study has been made.

The nursery plats used were three rows wide. Some were 1 rod long, others 3 rods long. The rows were 1 foot apart. This was true both as to rows within the plats and as to adjacent border rows of contiguous plats. Rows ran north and south except in the 1926 wheat nursery and in one section of the 1924 wheat nursery. The effect of direction of rows will be noted later.

The soil upon which the work was done is a naturally well-drained Wooster silt loam in a state of high fertility. Several different fields were represented. Data were gathered in five different years. Both oats and wheat were included.

METHODS OF ATTACK

Three general methods of attack are presented in this paper. First, the yield relation between adjacent border rows of contiguous three-row plats is compared with that between center rows of the same plats. The aim is to learn whether competition results are expressed in relatively greater contrasts between yields of border rows. The border rows were not protected from competition.

The second method is a comparison of center and border rows in three-row check plats in regard to variation. The check plats in a given field were all planted to one variety.

In the third method, correlation tables are used. Theoretical measures of competition effects are calculated and these are paired with relative yielding performance, time of maturity, and height.

Aside from these three general modes of attack, notes are made on the method of establishing an index of relative yield between contiguous plats when this yield is to be paired with a supposed index of competition for correlation studies. Direction of rows as bearing on competition is also noted.

BORDER-ROW CONTRASTS VERSUS CENTER-ROW CONTRASTS AS EVIDENCE OF COMPETITION

Assuming that competition of consequence is in operation, it would be expected that the plats would be depressed in yield when grown alongside of varieties offering the stronger competition. It would further be expected that the border rows of three-row plats would suffer more than the center rows. Conversely, increased growth, relatively greater in the border-rows would be expected in plats adjacent to weakly competing sorts.

If a relation exists between yield and ability to compete, the obvious result of effective competition in adjacent three-row plats would be to exaggerate the yield differences. Furthermore, unless the disturbing influence is felt equally by the border rows and center rows, the exaggeration will be greater between adjacent border rows of contiguous plats than between the center rows.

The first step, therefore, was to determine whether or not adjacent border rows show exaggerated yield differences as compared to center rows of the same adjacent plats. To learn this, using contiguous plats, the difference between adjacent border-row yields and also between center-row yields was found. To learn whether the difference between the border rows was greater than that between the center-rows, the center-row difference was subtracted from the border-row difference. An example assuming competition disturbance follows:

	Variety A			Variety B		
Row	1	2	3	1	2	3
Yield	100	100	110	80	90	90

Border-row difference = 110—80 = 30
Center-row difference = 100—90 = 10

Border-row minus center-row difference = +20

The border-row difference in this supposed case definitely exceeds the center-row difference. Such a condition would be looked for under effectual competition.

In Column 4, Table 1, in which data taken from the oats nurseries are shown, plus signs indicate that adjacent border-row differences

TABLE 1.—*Border row differences minus center row differences as an expression of competition between adjacent three-row plats in oats nurseries.*

Significant plus signs should indicate yield disturbances from competition.

Year	Length of row	Number of paired plats	Border difference minus center difference in bushels per acre
1921	3 rods	55	+1.35±0.489
1922	1 rod	94	—1.13±0.557
	3 rods	30	+1.98±0.801
1923	1 rod	141	—1.53±0.731
	3 rods	66	—1.63±0.587
1924	3 rods	36	+4.57±1.131
1925	3 rods	34	—0.27±0.591

were greater than center-row differences, while minus signs indicate the opposite condition.

That border-row differences were, on the whole, actually greater than center-row differences is hardly shown in this table. In results for one year only (1924) is there an indication that would warrant attention. It is possible that competition was exerting an influence that year. This will be considered in the discussion. Seasonal conditions in 1924 were above normal in favorableness for oat production.

TABLE 2.—*Border row differences minus center row differences as an expression of competition between adjacent three-row plats in wheat nurseries.*

Significant plus signs should indicate yield disturbances from competition.

Year	Length of row	Number of paired plats	Border difference minus center difference in bushels per acre
1921	1 rod	137	—0.11±0.193
	3 rods	164	+0.27±0.156
1922	1 rod	59	+0.23±0.414
	3 rods	126	—0.05±0.137
1924	3 rods	153	+0.40±0.175
1925	3 rods	89	+0.08±0.183
1926	3 rods	78	+0.37±0.228

In Table 2 are found similar tabulations for wheat nurseries. The values in Column 4 are again not significantly positive. It seems, therefore, that competition has acted weakly if at all in bringing about a contrast between adjacent border rows greater than exists between center rows of contiguous three-row plats.

VARIABILITY OF BORDER ROWS VERSUS CENTER ROWS AS EVIDENCE OF COMPETITION

Every sixth plat in the plantings described above was a check. All checks were planted to a uniform variety of known merit. These checks were in rows 3 rods long. They were harvested, however, in 1-rod sections. Rows of different lengths were therefore available for study.

If outer rows are subject to depressed or increased yields as the adjacent varieties bid more or less strongly for moisture, mineral elements, or light, it might be expected that in these check plats a greater variability would be found among border-rows than among center rows. Since the checks occur at every sixth location, they come in contact with a variety of competitors. The strong competitors might tend to depress the border rows of the check plats, while the weak competitors might allow an enhancement in the check border rows. As a result the check border rows should show more fluctuation than the center rows which are constantly adjacent to rows of their own variety.

In Tables 3, 4, and 5 are presented comparisons of the variability in border and center rows of three-row nursery plats. The data are from checks, except where otherwise noted.

TABLE 3.—*Comparative standard deviations in bushels per acre of center and border rows in three-row plats.*[a]

Data from check plats in oats variety nurseries.

Year	1-rod plats		3-rod plats	
	Center rows	Outer rows	Center rows	Outer rows
1921	4.98 (n=21)	4.50 (n=42)	3.85 (n=7)	3.22 (n=14)
1922	5.41 (n=18)	8.35 (n=36)	4.36 (n=6)	3.79 (n=12)
1923	11.94 (n=21)	9.49 (n=42)	7.64 (n=7)	6.06 (n=14)
1924	10.27 (n=21)	12.40 (n=42)	5.38 (n=7)	6.15 (n=14)
1925	10.15 (n=18)	9.69 (n=36)	6.07 (n=6)	7.17 (n=12)
Summary[b]	9.05±0.434 (n=99)	9.26±0.314 (n=198)	5.64±0.468 (n=33)	5.48±0.322 (n=66)

[a] Standard Deviation = $\sqrt{\frac{\Sigma V^2 - na^2}{n}}$, where V = a variate, n = the number, and a = the average.

[b] To find a representative standard deviation for more than one group of variates the value $\Sigma V^2 - na^2$ is found for each group. The summation of these values for all groups is divided by the total number of variates in all groups, and the square root is extracted. By this method the deviations are measured each from the mean of its own group and are summarized as though the means of all groups were alike.

TABLE 4.—*Comparative standard deviations in bushels per acre of center and border rows in nursery plats.*

Data from oats method study nurseries.[a]

Year	1-rod plats		3-rod plats	
	Center rows	Border rows	Center rows	Border rows
1924	10.31 (n=108)	10.40 (n=216)	6.40 (n=36)	7.67 (n=72)
1925	8.81 (n=149)	9.75 (n=297)	6.70 (n=54)	6.49 (n=108)
1926	8.89 (n=207)	10.04 (n=197)	6.44 (n=67)	7.53 (n=64)
Summary	9.21±0.204 (n=464)	10.03±0.180 (n=710)	6.52±0.248 (n=157)	7.13±0.218 (n=244)

[a] In the oats method study nurseries, three varieties were planted in continuous series as follows: Miami, Ohio 201, and Fulghum. The plats were three rows wide in 1924, in 1925 they were three and five, and in 1926 they were six. Only one middle-row was used in the five-row plats, but the two middle-rows were used in the six-row plats. The deviation of each variety is calculated from its own mean, also the deviation of the center rows and of the border rows.

There is little evidence in these tables that competition has served to bring about greater variability in border rows than obtains in center rows. In Table 4 the border rows do seem to be the more variable. The differences, however, seem hardly well enough established to war-

TABLE 5.—*Comparative standard deviation in bushels per acre of center and border rows in three-row plats.*

Data from check plats in wheat variety nurseries.

Year	1-rod plats		3-rod plats	
	Center rows	Border rows	Center rows	Border rows
1921	3.52 (n=84)	4.20 (n=168)	2.33 (n=27)	2.62 (n=54)
1922	2.19 (n=63)	2.92 (n=126)	0.96 (n=21)	1.86 (n=42)
1924	3.58 (n=84)	3.70 (n=168)	2.03 (n=28)	2.08 (n=56)
1925	3.71 (n=42)	4.03 (n=84)	2.28 (n=14)	1.97 (n=28)
1925[a]	4.65 (n=108)	4.53 (n=216)	2.99 (n=36)	2.58 (n=72)
1926	5.75 (n=42)	5.35 (n=84)	4.29 (n=14)	3.83 (n=28)
Summary	3.99±0.092 (n=423)	4.15±0.068 (n=846)	2.58±0.104 (n=140)	2.51±0.072 (n=280)

[a] The 1925 method study wheat planting in continuous series of three-row plats as follows: Trumbull, Gladden, Fulhio, Trumbull, Gladden, Fulhio, etc. The deviation of each variety is calculated from its own mean, as is also the deviation of the center rows and of the border rows.

rant an assumption of competition when the accompanying tables (3 and 5) show indifferent results.

Again it may be that the manner of planting had something to do with the performance of this test. The method study oats reported in Table 4 were planted to three varieties, *v.z.*, Miami, Ohio 201, and Fulghum. They were in continuous series, that is the three sorts in the order named were grown in plats 1, 2, and 3, again in plats 4, 5, and 6, etc. Miami is well adapted, high-yielding, mid-season; Ohio 201 is tall, coarse, rather late, productive; and Fulghum is early, short, productive. By this method of planting a rather contrasting variety was placed on each side of every plat.

INDIFFERENT CORRELATION BETWEEN YIELD AND APPARENT COMPETING STRENGTH

As a further inquiry into the matter of competition, coefficients of correlation between relative yield and presumed competitive effect were calculated. To measure supposed results of competition, an abstraction which has been called a competition-index was established. The method of computing the competition-index is patterned after that reported by Stadler (4), although the procedure here followed is slightly simplified.

Given two adjacent plats, one yielding high and the other low, the competition-index is a measure of the enhancement of border-row yield in the high-yielding plat plus the suppression of border-row yield in the low-yielding plat.

For a given three-row plat, which may be called A, the gain or loss of the right border row as compared to the center row is found. For the contiguous plat to the right (B) a similar calculation, using the left border row, is made. The value for Plat B is subtracted from the value of Plat A. Since the algebraic difference is assigned to Plat A, this should make A's competition-index positive if A offers the stronger competition and negative if it offers the weaker.

As a yield-index for Plat A in relation to Plat B the grain weight of B, using the average for all three rows, is subtracted from that of A and the algebraic difference assigned. This gives A a positive yield-index if it yields more than B and a negative yield-index if it yields less. An example of the competition-index and yield-index taken from a page of nursery wheat notes follows:

Plat	47	48	49	50	51
Row yield in grams	204 203 211	167 184 155	230 254 233	213 208 200	160 166 142
Border-row minus center row	+8	—17 —29	—24 —21	+ 5 — 8	— 6
Competition-index	+25	— 5	—26	— 2	
Yield-index	+37	—70	+32	+51	

For a given plat it can be seen that any enhancement of its right border-row yield over its center-row yield will contribute to a plus competition-index. And in the neighboring plat to the right any suppression of left border-row yield in comparison to center-row yield will also contribute to a plus competition-index for the left-hand plat.

For instance, in the above illustration the right border row of Plat 47 yields 8 grams more than its center-row. This contributes 8 grams toward a positive competition-index. The left border row of Plat 48 is apparently suppressed by 17 grams. This minus quantity being subtracted, further contributes toward a positive competition-index for Plat 47, making a total competition-index of 8—(—17) =+25 grams. The competition-index is therefore an expression for two contiguous plats of both the increase in border-row yield for the higher yielding one and the suppression in border-row yield for the lower.

The yield-index in the illustration, being merely the difference between the two plat yields, is +37 grams for Plat 47. It is plus because the right is always subtracted from the left.

In Tables 6 and 7 will be found Pearson's coefficient of correlation between competition-index and yield-index. In one case only, that of three rod-row oats in 1921, is there a suggestion that yields have been disturbed by competition.

ALL ROWS OF THREE-ROW PLATS USED IN ESTABLISHING YIELD-INDEX FOR COMPETITION STUDY

The discussion under this heading will probably be of interest only to those who are concerned about methods of detecting competition

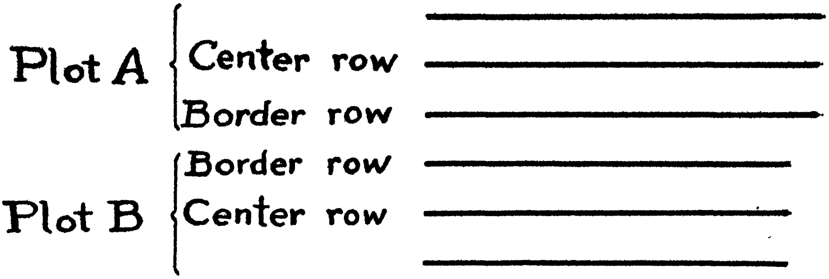

FIG. 1

among nursery plats. The aim is to show that, at least where competition is producing a mild effect, the yield-index for adjacent plats should be determined not by comparing the yields only from protected center-rows, but by comparing the total yields for the two plats. In other words, among adjoining three-row plats both border and center rows should be used in arriving at the yields from which the yield-index is found.

TABLE 6.—*Pearson's coefficients of correlation between yield and competing strength for adjacent three-row plats in oats. Yields are based on the average of the three rows.*

Year	Length of plats	Number of paired plats	γ
1921	3 rods	55	+0.350±0.080
1922	1 rod	95	—0.060±0.067
	3 rods	30	+0.178±0.119
1923	1 rod	142	—0.126±0.056
	3 rods	63	—0.081±0.084
1924	3 rods	36	+0.051±0.112
1925	3 rods	34	+0.092±0.115

TABLE 7.—*Pearson's coefficients of correlation between yield and competing strength for adjcent three-row plats in wheat. Yields are based on the average of the three rows.*

Year	Length of plats	Number of paired plats	γ
1921	1 rod	125	+0.062±0.060
	3 rods	162	+0.054±0.053
1922	1 rod	60	+0.028±0.087
	3 rods	127	—0.136±0.059
1924	3 rods	153	+0.159±0.053
1925	3 rods	89	+0.173±0.069
1926	3 rods	76	+0.118±0.075

The reason is, that if one is attempting to find a correlation between the previously described yield-index and competition-index and if he uses only center rows for the yield-index, independent fluctuations of these center rows, when approximately greater than the difference in yield between the plats, tends to produce opposite signs of the indices.

An illustration will make this clearer. In Fig. 1 the length of the lines may represent yield. Keeping this figure in mind and dropping the matter of competition, the following outline shows how fluctuations in row yields would affect the signs of Plat A yield-index and competition-index when only center rows determine the yield-index. The signs in the outline indicate not direction of change but merely the condition obtaining after independent fluctuation has occurred.

Row	Direction of fluctuation	Distance	Sign of yield-index	Sign of competition-index
Center A	Upward	Any distance	+	—
	Downward	To level of "Center B"	+	+
	Downward	Beyond level of "Center B"	—	+
Border A	Upward	Any distance	+	+
	Downward	Any distance	+	—
Center B	Upward	To level of "Center A"	+	+
	Upward	Beyond level of "Center A"	—	+
	Downward	Any distance	+	—
Border B	Upward	Any distance	+	—
	Downward	Any distance	+	+

If Plat A happened to be the lower instead of the higher yielding plat, all signs would merely be reversed.

It will be seen that, as stated above, independent fluctuation of the center rows when approximately greater than the yield difference between the plats tends to produce opposite signs in the two indices. Such fluctuations will contribute toward a negative correlation.

Independent fluctuations of the border rows, assuming they are as likely to be in one direction as the other, should tend to produce a neutral correlation, since if in one direction signs become alike while if in the other direction signs become opposite.

On the whole, then, major fluctuations tend in the direction of a negative correlation of the measures here employed.

In Tables 8 and 9 will be found the coefficients of correlation between the yield-index (using center rows only) and the so-called competition-index. None of the values are high, but the persistence of the negative sign would make it seem that chance fluctuations greater than those resulting from competition have determined the sign of γ, and that the method should not be used with these data to detect competition effects. This is no evidence against the use of only center rows for the yield-index where competition is exerting a major influence in determining the relative yield of center and border rows.

DIRECTION OF ROWS, TIME OF MATURITY, AND HEIGHT, AS AFFECTING COMPETITION

The 1924 wheat nursery was planted in two beds. In one the rows ran north and south and in the other they ran east and west. The two were compared to see if direction of rows was making a difference in competition.

A method of measuring for competition different from any discussed above was used in this study. As in Tables 6 to 9, relative border-row yield was assumed to be a function of competition. Consider two adjacent three-row plats, A and B. If A is the left-hand plat and is offering the stronger competition its right-hand border-row should yield something more than 1 in terms of its center row. On the other hand, the left border row of B should yield something less than 1 in terms of B's center row. Effective competition then should be accompanied by a negative correlation between the relative border row yields of contiguous plats.

TABLE 8.—*Pearson's coefficients of correlation between yield and competing strength for adjacent three-row plats in oats.*

Yields are based on center rows only.

Year	Length of plats	Number of paired plats	γ
1921	3 rods	55	—0.441±0.073
1922	1 rod	95	—0.341±0.061
	3 rods	30	—0.363±0.108
1923	1 rod	142	—0.440±0.046
	3 rods	63	—0.523±0.062
1924	3 rods	36	—0.465±0.088
1925	3 rods	34	—0.178±0.112

TABLE 9.—*Pearson's coefficients of correlation between yield and competing strength for adjacent three-row plats in wheat.*

Yields are based on center rows only.

Year	Length of plats	Number of paired plats	γ
1921	1 rod	125	—0.472±0.047
	3 rods	162	—0.408±0.044
1922	1 rod	60	—0.580±0.056
	3 rods	127	—0.488±0.045
1924	3 rods	153	—0.337±0.048
1925	3 rods	89	—0.301±0.065
1926	3 rods	78	—0.178±0.074

It is to be understood that relative border-row yield means yield in relation to the center row, as 1.05 or 0.95 times the center row. It is further to be understood that a paired measure consists of these relative yields for adjacent border rows of contiguous plats. Only plats differing in yield by more than a rate of 3 pecks per acre were paired.

Pearson's coefficient of correlation between relative border-row yields was +0.161 ± 0.073 ($n=78$) for the north and south rows. The correlation for east and west rows was + 0.005 ± 0.078 ($n=75$). In neither case is there a suggestion of yield disturbance from competition.

The relative border yield of each plat was then paired with the difference in date of maturity between it and the adjacent plat. Plats differing in maturity by one day or more were paired. The plat in question was given a minus sign if earlier and a plus sign if later. Correlation coefficients of only +0.024 ±0.062 (n = 118) for north and south rows and of only +0.031 ±0.014 (n = 104) for east and west rows were obtained. Since neither result is significant, evidence is not found to indicate that time of maturity was associated with effective competition in rows of either direction.

Using plats adjacent to others differing by 1 inch or more in height and assigning the plats in question plus signs if they were the taller and negative signs if the shorter, correlation coefficients between relative border-row yields and the difference in height were calculated. For north and south rows the correlation was —0.252 ±0.082 (n = 131). The east and west plats were divided first into pairs in which the taller member was to the north and second into pairs in which the taller was to the south. Coefficients of correlation were: Tall plats to the north, +0.022 ±0.080 (n = 71); tall plats to the south, +0.268 ±0.085 (n = 54). No appreciable correlation has yet been found.

The numbers reported in the two preceding paragraphs are greater than the actual numbers of plats used, since if contiguous plats differed by a day or more in maturity or by an inch or more in height, the relative border rows of each plat were paired with this difference in maturity or height.

A further note can be made on the direction of rows as a factor in competition. The rows of the 1926 wheat nursery extended east and west. Rows in all plantings of other years, except the one section in 1924, ran north and south. A study of Tables 2, 5, and 7 does not show that the 1926 wheat was subject to competition effects while other wheat plantings were not.

DISCUSSION

The aim in this study was to learn whether the competition, which undoubtedly exists, is severe enough to demand practical consideration in outlining nursery yield tests. In these test plats all varieties were planted at the same time, and they generally did not vary markedly in time of maturity, vigor of growth, shading ability, or foraging power. Furthermore, the results presented above, except for the method study tests are summaries of a considerable number of paired varieties. There may well be isolated pairs in which some one or more contrasting qualities are responsible for yield relations quite different from the average. Good nursery practice, however, is to group short or weakly growing sorts together so that prominent contrasts will seldom appear side by side.

Competition is undoubtedly playing some part in modifying yields in the Wooster cereal nurseries, but the influence seems to be so weak that grosser errors obscure it. The few cases in which the data suggest measurable competition are of doubtful significance. For instance, the method of subtracting center-row differences from adjacent border-row differences would indicate that the oats variety nursery was affected by competition in 1924 (Table 1). Comparing the standard deviations of center and border rows in check plats (Table 3) would tend to support Table 1. The same planting, however, shows a decidedly indifferent correlation between yield and competing strength (Table 6).

By the correlation method the 1921 oats indicate a slight relation between yield and competing strength (Table 6), but the two other methods of attack (Tables 9 and 3) give indifferent results for the same year.

As a whole, Table 4, in which are compared the standard deviations of border and center rows of oats method study nursery plats, seems to support the idea that border rows are more variable than center rows. It will be remembered that in these tests Miami, Ohio 201, and Fulghum were planted in continuous series. Each variety was therefore alongside of at least one decidedly contrasted sort. Perhaps under such conditions border-row yields are somewhat disturbed by competition. At least the practice of grouping varieties similar in growth and time of maturity would appear to be a good precaution.

The wheat plantings have been less erratic in their performance throughout than the oats. About the only place where effective competition in wheat would be suspected is in comparing standard deviations for center and border rows among the check plats of 1922 (Table 5). The differences are 0.73 ±0.180 bushel and 0.90 ±0.206 bushel for 1-rod and 3-rod plats, respectively. Studying the 1922 wheat data from the standpoint of border-row differences minus adjacent center-row differences (Table 2) and also by attempting to establish a correlation between yield and competing strength (Table 7), fails, however, to give similar indications.

The nursery fields are kept high in fertility. Oats have averaged about 60 bushels per acre and wheat 30 bushels. The exact relation of good fertility to competition cannot be stated, but there seems reason to expect a more moderate effect as soil conditions approach the optimum for plant growth. It would seem that as the available plant food materials in the soil approach the optimum quantity the better foragers would become less troublesome in robbing the weaker or slower sorts of needed materials. Under ideal soil conditions one would think that, regardless of adjacent varieties, the normal plant's ability to utilize sunlight and food materials would constitute its most serious limitation. The tendency for shading to be a factor in competition might, on the other hand, be intensified by high fertility.

It would be of interest to know why the findings in this study generally agree with the report by Love for New York, but disagree with the results of Hayes and Arny at Minnesota, Kisselbach at Nebraska, and Stadler at Missouri. Considering the difference in effective rainfall between Wooster and Ithaca, on the one hand, and the stations bordering the Great Plains area, on the other, it seems easily thinkable that climatological factors form a basis for the apparently more severe competition in the Middle West.

SUMMARY

1. In the fertile small grain nurseries at Wooster with rows 1 foot apart, only occasional indications of yield disturbance from competition were found.

2. In attempting to detect effects of competition by establishing a correlation between relative yield and competing strength among adjacent three-row plats, the relative yield may have to be established by using all three rows. This is to overcome a tendency toward a negative correlation of the measures, brought about by comparatively gross independent fluctuations of the center rows where only center rows are used to establish the relative yields.

3. In the material studied, direction of rows did not measureably affect the tendency for competition to alter yields.

4. If varieties generally similar in growth and time of maturity are grouped, there seems to be little reason for further concern about the matter of competition in the types of nursery plantings studied at Wooster and under Wooster soil and climatic conditions.

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ELECTRODIALYSIS OF SOIL: 1. A STUDY OF THE METHOD[1]

HARRY HUMFELD AND A. O. ALBEN[2]

A preliminary report on the study of base exchange in soil by electrodialysis, using a modification of the Mattson cell has been submitted for publication (6)[3] and should appear at an early date. It is the purpose of this paper to present the experimental data secured in the work referred to and to give more detailed information regarding the technic of the method.

Reference has been made previously to the work of Hissink (15) and Gedroiz (12) on base exchange and to that of Cameron and Bell (4), König and co-workers (17), and Mattson (20) on the electrodialysis of minerals and soils.

The principle of electrodialysis has found application in the past along various lines. Dhéré and Gorgeleuski (7), Adolf and Pauli (1), Bernard and Beaver (3), and others (8, 10, 22) have used electrodialysis on blood serums with various objects in view. Lisbonne and Vielquin (18) and Friche, et al (11) employed electrodialysis to separate and study enzymes. Shepard, et al (23) purified gelatin by electrodialysis and Bechhold and Rosenberg (2) followed the same method to purify both gelatin and glue. Foster and Schmidt (9) used electrodialysis to separate hexone bases from certain proteins. Taylor, et al (24) studied the effect of electrodialysis on insulin. Harvey (13) in 1925 and Hoffman and Gortner (16) in the same year purified agar by electrodialysis. Heyman (14) in 1925 found that electrodialysis was about 100 times as efficient as either dialysis or electroendosmosis in removing electrolytes from colloidal solutions.

Moore, et al (21) employed electrodialysis as a means of studying the biochemical differences in abnormal apple tissue. Mattson (20) recently applied electrodialysis to the determination of the replaceable bases in colloids obtained from soils and found a very close agreement between the results secured and those obtained by the use of normal ammonium chloride.

The cell used by Mattson consisted of three chambers, the center one being separated from the two outside ones by parchment paper.

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[2] Research Fellows in Soils. The authors wish to thank Dr. Paul Emerson for helpful suggestions, Dr. P. E. Brown for reading the manuscript, and Dr. N. A. Clark for the use of his laboratories and equipment.

[3] Reference by number is to "Literature Cited," p. 992.

The center chamber contained the material to be dialyzed. Suspended in the solution in the two outside chambers were platinum gauze electrodes large enough to extend to the bottom of each chamber. The cell consisted of three pieces of U-shaped soft rubber separated by two sheets of parchment paper. The outside plates were made of hard rubber. The whole was fastened together by a number of bolts. The parchment paper was prevented from bulging by a glass lattice support. Outlets for the withdrawal of the dialysates were located at the bottom of each of the two outside chambers.

EXPERIMENTAL

While the Mattson cell gave good results in preliminary studies, some minor changes in construction, which will be described later, were found to constitute a distinct improvement.

Parchment paper of the grade C.S. Co.10040 was used. A 110 volt direct current was employed, instead of the 220 volt direct current used by Mattson. A 25 watt lamp was used in series in the circuit to keep the temperature from rising above 50°C. The soil was a virgin Carrington loam obtained from the Agronomy farm of the Iowa Agricultural Experiment Station.

The bases obtained in the dialysate were titrated with HCl, using two indicators, phenolphthalein first and, when it became colorless, adding methyl red and titrating with the same acid to the end-point. The acids were titrated with NaOH, using phenolphthalein.

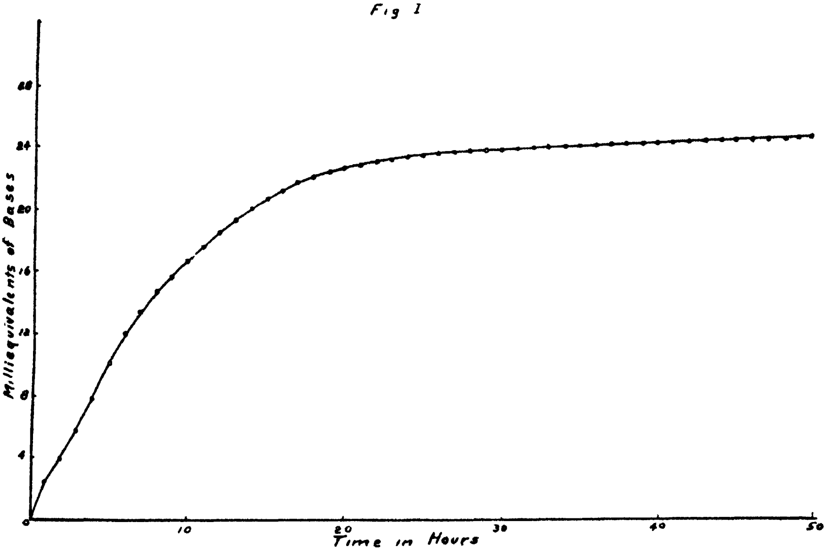
Mattson found 28.937 milli-equivalents of bases and 3.375 milli-equivalents of acids removed from Sharkey clay in 22 hours; while in the Manor loam only 3.553 milli-equivalents of bases and 0.346 milli-equivalent of acids were removed in five hours. As the final titration showed that the two soils yielded only 0.090 and 0.043 milli-equivalents of bases, respectively, during the last hourly extraction, he concluded that a fairly definite end-point had been reached.

In this work a sample of 100 grams of Carrington loam was extracted in the same manner, making changes of solution every hour for 50 hours. After 20 hours it was found that the solution containing the bases was acid to phenolphthalein; and, while in all subsequent changes the solutions remained basic to methyl red, the amount of acid required for titration decreased steadily.

As the solution tended to approach a neutral reaction it was noticed that a whitish flocculent precipitate, apparently aluminum hydroxide, appeared in increasing amounts. With further dialysis and subsequent changes of solution the precipitate changed to a brown color, indicating increasing amounts of iron hydroxide and possibly decreasing amounts of aluminum.

If the neutral point of phenolphthalein is taken as the end-point, then the Carrington loam used contained a total of 18.150 milli-equivalents of bases and 1.126 milli-equivalents of acids. However, if methyl red is used as the indicator and the end-point is taken when it requires only 0.10 cc of N/10 acid to make the solution neutral to this indicator, this end-point is not reached until after 50 hours of dialysis. The bases extracted then amount to an additional 6.255 milli-equivalents, or a total of 24.405. It is believed that this is a better end-point than the one used by Mattson. Titration with phenolphthalein as an indicator does not take into account the aluminum and iron present. According to Clark (5), phenolphthalein changes at pH 9.7. Magistad (19) shows that at this point Al_2O_3 may be soluble to the extent of approximately 200 p.p.m. Qualitative tests have shown that appreciable quantities of aluminum and iron are present. A later paper will give quantitative results along this line.

Fig 1



RATE OF EXTRACTION

The results of the experiment on the Carrington loam are shown in Fig. 1. The curve indicates that there is a consistent decrease in the rate at which the cations are extracted and that there is a fairly rapid decrease until a rate is reached at which the amount extracted is practically negligible. Hence, for all practical purposes, it may be concluded that all the exchangeable bases have been extracted.

As it is rather inconvenient to change solutions every hour, it was thought that it might be possible to allow a longer period of time to elapse between changes, accordingly the time of dialysis was extended to 6- and to 12-hour intervals. The results are show in Table 1.

TABLE 1.—*Results of 6-hour and 12-hour changes.*

Time in hours	Temperature in degrees C	Ammeter reading in amperes	M. E., bases	M. E., acids
6	50	0.40	7.654	1.288
18	50	0.26	7.858	0.727
24	51	0.21	5.138	0.358
30	42	0.10	1.748	0.134
42	40	0.09	1.000	0.134
54	40	0.07	0.291	0.123
66	39	0.06	0.135	0.079
		Total	23.824	2.843

Also dialyses were made using time intervals of 1 hour, 1 hour, 2 hours, 4 hours, and 12 hours. The results are shown in Table 2. The results show that the quantity of bases extracted is to some extent dependent upon time, and that if the temperature can be kept down, it is not necessary to change solutions every hour.

TABLE 2.—*Results of 1-hour, 1-hour, 2-hour, 4-hour, and 12-hour changes.*

Time in hours	Temperature in degrees C	Ammeter reading in amperes	M. E., bases	M. E., acids
1	31	0.16	1.583	0.291
2	32	0.13	1.612	0.224
4	35	0.14	3.108	0.190
8	35	0.17	4.283	0.268
20	34	0.16	6.701	0.492
26	40	0.11	3.264	0.167
32	41	0.11	1.894	0.190
44	40	0.10	1.457	0.179
54	37	0.08	0.301	0.089
		Total	24.201	2.090

Fig. 2 shows very clearly the rate of extraction. If this curve is compared with that obtained by changing solutions every hour, it will be seen that they are almost identical, so that it may be concluded that the time interval can be extended and the number of changes reduced without appreciably altering the rate of dialysis.

CHANGE OF VOLTAGE

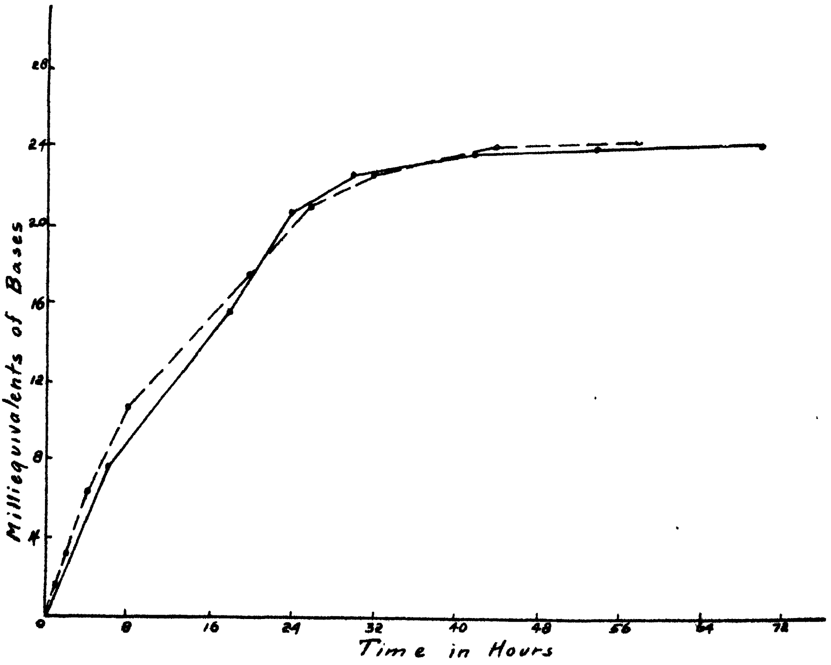
Since in many laboratories 110 volt direct current is not available, it was thought that a comparison of the results obtained with 110 volt D. C. with those secured at a lower voltage would be of interest and value. Therefore, a small rectifier rated at 7.5 to 15 volts operated by 110 A. C. was used. The results are shown in Table 3.

TABLE 3.—*Results with 7.5 to 15 volt rectifier.*

Time in hours	Temperature in degrees C	Ammeter reading in amperes	M. E., bases	M. E., acids
10	27	0.08	2.933	0.448
16	24	0.06	1.506	0.090
22	23	0.03	1.136	0.090
35	28	0.08	3.361	0.213
46	31	0.08	4.543	0.336
59	26	0.04	1.564	0.078
69	28	0.03	1.136	0.067
83	30	0.03	0.884	0.045
93	30	0.02	1.049	0.056
107	27	0.02	0.544	0.045
117	27	0.02	0.651	0.045
131	27	0.02	0.515	0.034
143	28	0.02	0.194	0.045
		Total	20.019	1.592

The data obtained show that the bases and acids are being removed at too slow a rate for this method to be of practical value for the determination of total replaceable bases. When compared with the results obtained with 110 D.C., it will be seen that the end-point has not been reached at the end of 143 hours. Furthermore, the slowing

Fig II



down of the rate indicates that the time required for complete removal of bases would be excessive.

Better results were obtained by connecting a one-eighth horse power A.C. motor to a one-eighth horse power D. C. motor reversed. This hookup gave a voltage of between 50 and 55. The rate of dialysis compared very favorably with the rate obtained with 110 volts D.C. The temperature remained lower and a quite definite end-point was obtained. Table 4 shows the detailed data.

TABLE 4.—*Results with 1/8 h. p. A. C. motor and 1/8 h. p. D. C. motor reversed.*

Time in hours	Temperature in degrees C	Ammeter reading in amperes	M. E., base	M. E., acid
2	27	0.09	1.144	0.315
4	28	0.07	1.481	0.112
8	29	0.09	3.010	0.425
12	30	0.09	3.455	0.269
23	30	0.10	5.406	0.313
29	35	0.16	3.576	0.224
36	44	0.19	4.190	0.425
48	36	0.08	1.529	0.315
52	32	0.05	0.301	0.147
		Total	24.092	2.545

It would seem that if the equipment mentioned is available reasonably satisfactory results may be expected, but if equipment must be bought it would be preferable to buy a higher voltage outfit.

COOLING

Temperature control would seem to be desirable if by such means solubility effects could be reduced to a minimum. Mattson endeavored to keep down the temperature in the cell by means of a 25 to 50 watt lamp in series. The same means were used in these experiments. However, it was observed that at times the temperature would rise as high as 50°C.

In order to control temperature more effectively, the following modification of the cell was made. The lattice of glass rods on each side of the parchment paper was replaced by two thin glass tubes bent in the shape of a grid. The grids were connected to the water system by means of rubber tubing, and cold tap water was run through them continuously. The results were entirely satisfactory, the temperature being kept between 18° and 22° C by this means.

Later, another grid was placed in the center compartment containing the soil, thereby eliminating any possibility of excessive temperature in the soil itself. This method of cooling makes it possbile to eliminate the lamp from the circuit. In all subsequent work this system of cooling has been successfully employed.

CHANGING THE DIALYSATE

An attempt was made to complete the dialysis without changing the solutions in the cell. This attempt was unsuccessful as it appears that a maximum concentration is reached after about three to four hours, and no appreciable increase in the quantity of bases is obtained with a single change at a longer period. Further experiments indicate that changes at 3-, 6-, and 12-hour intervals give satisfactory results, and that when Carrington loam is used an end-point is reached in about five changes, a total time of 45 hours being required. Experiments indicate that the total time required depends considerably upon the soil used, due, no doubt, to the varying amounts of bases present in different soils.

It was found that if the solutions were not changed every hour but were run for 12 hours without a change, the end-point of Mattson was reached at a considerably later stage. Titration with methyl red as the indicator shows that an appreciable amount of bases is brought into solution which cannot be titrated with phenolphthalein as the indicator. These bases separate out as flocculent precipitates which are first white and later become brownish in color. Indications are that these bases are largely aluminum and iron, and it is believed that they must also be considered as being replaceable.

Mattson's data giving total milli-equivalents of bases as determined by titration could not include the replaceable aluminum and iron present in the solution as this becomes colorless to phenolphthalein before the hydroxides of these bases react with the acid used for titration. Presumably, then, his data include only milli-equivalents of such cations as Ca, Mg, K, and Na. Titration with methyl red as the indicator gives an end-point with a sufficiently low pH of the solution to insure neutralization of the aluminum and iron present. Results indicate that after this end-point is reached further dialysis gives a small but fairly constant titration, the acids and bases going into solution in approximately equivalent amounts. This may be due to the hydrolysis of the comparatively insoluble residue. When this point is reached it may be assumed that hydrogen has replaced all of the replaceable bases and that the soil is now entirely unsaturated with respect to bases.

The Carrington loam used in these experiments appeared after dialysis to be in good physical condition. This was undoubtedly an unsaturated soil, but there was no evidence from its appearance to show deflocculation which might have been expected.

It is well known that hydrogen-ion concentration has an important bearing on practically all soil problems, therefore, the pH of the soil was determined both before and after dialysis by means of the quinhydrone electrode. The original soil had a pH of 5.7, while the soil after dialysis had a pH of 3.0 to 3.1.

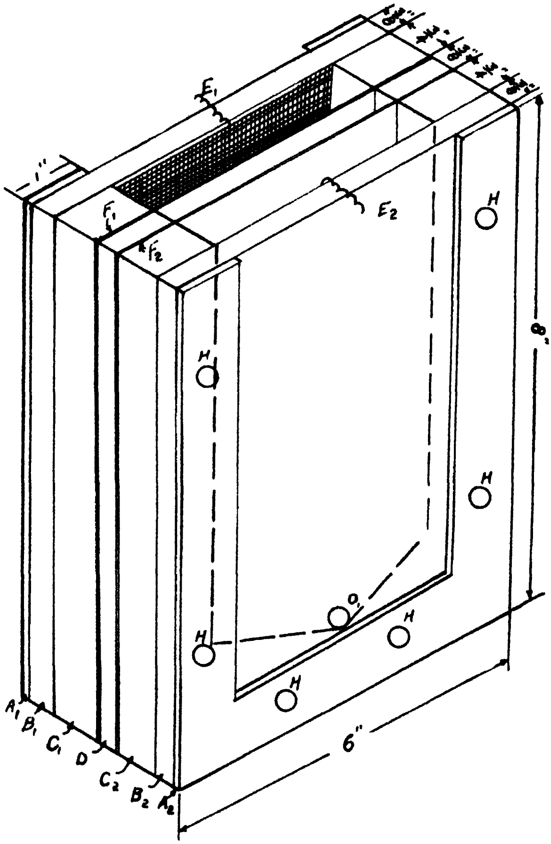


Fig. III. Apparatus for electrodialysis of soils.

A very indefinite titration end-point, due to absorption of the indicator, was often secured when methyl red was used. The absorption seems to be most noticeable in the presence of aluminum and iron precipitates. Studies are being made to overcome this difficulty.

DESCRIPTION OF APPARATUS

The cell previously described has been modified from time to time and a description of the cell now in use follows.

The cell is three chambered. The dimensions are shown in Fig.3. B_1 and B_2 are two pieces of soft plate rubber. C_1, C_2, and D are U-shaped pieces of soft plate rubber and A_1 and A_2 are U-shaped pieces of iron 1/8 inch thick and 1 inch wide. At H are holes for the ¼inch bolts which hold the pieces together. O is an opening for draining the cell. A glass stopcock may be inserted to facilitate the changing of solutions. E_1 and E_2 are 52-mesh platinum gauze electrodes 4 by 6 inches in size. The bolts are provided with wing nuts for convenience in taking the cell apart for cleaning. F_1 and F_2 are parchment paper membranes. The paper is dialyzed for approximately one hour in order to remove all soluble salts.

A suitable voltmeter and ammeter are placed in the circuit. An ammeter having a capacity of 3 or 5 amperes usually will be large enough to take care of several cells. If only alternating current is available, a motor-generator can be used to supply the direct current.

SUMMARY

1. Electrodialysis of soils seems to be a promising method for studying the problem of base exchange.
2. Certain modifications of the method as used by Mattson result in a distinct improvement.
3. The use of a rectifier, capable of delivering a maximum of 15 volts D.C. was found to give too slow a rate of dialysis for practical purposes. A motor generator delivery 50 to 55 volts was found to give satisfactory results.
4. Temperature control was effected by means of a cooling system which permitted of the elimination of the lamp from the circuit.
5. Changing the solution every hour was found to be unnecessary. A longer period between changes did not reduce the rate of dialysis.
6. In the determination of the total replaceable bases by titration of the dialysate, methyl red is preferable to phenolphthalein as an indicator.

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IMPROVEMENT OF PERMANENT BLUEGRASS PASTURES WITH SWEET CLOVER[1]

L. F. GRABER[2]

About 231,000,000 acres of land, constituting approximately one-ninth of the total land area of the United States, is classified as "humid grassland pasture." Much of this is located in the north central and eastern states and such pastures are made up largely of bluegrass (*Poa pratensis*) in mixture with varying amounts of redtop (*Agrostis alba*), white clover (*Trifolium repens*), and other grasses and legumes. Popular comment has dealt largely with the unproductivity of such pastures and the superiority of sweet clover by virtue of its greater carrying capacity and its ability to supply pasturage during the dry periods of the summer, as well as during the early spring months. This treatise is an attempt to show, with limited data, how sweet clover may be utilized to increase and extend the productivity of permanent bluegrass pastures which now largely occupy land that is too rough to till.

Too often the failure of bluegrass to yield satisfactory returns has been ascribed to an exhaustion of the fertility of the soil when in reality the plant itself has become exhausted. Heavy premature grazing occasioned by increasing numbers of livestock has reduced, in many cases, the organic food reserves of the rhizomes and roots of bluegrass and other pasture plants to such a degree that such plants become unproductive even on very fertile soils. Where soils are deficient in fertility growth is, of course, limited accordingly, but it is also true that where such deficiencies do not occur, growth is limited by deficiencies in stored organic foods within the plant. Such results occur from continuous premature overgrazing.

No effort is made in this paper to establish evidence, either pro or con, that organic reserve foods may become limiting factors in the growth of perennial herbaceous plants, as indicated by previous statements, but an attempt will be made to offer certain suggestions, with some data for their support, as to practical means for the improvement of permanent bluegrass pastures.

These suggestions are based largely on the established value and popularity of sweet clover (*Melilotus alba*) for soil improvement and for grazing purposes. The utilization of this legume and other plants for temporary early spring pasturing will make possible, to a considerable degree, the practice of a "deferred" system of grazing permanent bluegrass pastures. This has proved valuable in the management of grazing lands in western states. In effect, "deferred" grazing is based on the principle of permitting such maturity of the top growth necessary to provide for adequate manufacture, translocation, and storage of food reserves in the roots, rhizomes, corms, or other storage organs of pasture grasses which is essential for the maintenance of their subsequent productivity.

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[1] Published with approval of the Director of the Wisconsin Agricultural Experiment Station, Madison, Wisc. Received for publication Sept. 3, 1927.

[2] Professor of Agronomy.

Winter rye, which has a vigorous and a much earlier spring growth than sweet clover, will in many places furnish pasturage until sweet clover has made sufficient progress to be grazed judiciously. Temporary pastures such as these may be grazed while the bluegrass is in those early vegetative stages of growth during which previously stored organic foods are being abundantly utilized for the production of new top growth. They make possible the avoidance of heavy and close premature grazing of permanent pastures until the bluegrass has headed or become sufficiently mature to have had an opportunity to replenish the supply of stored foods previously utilized in the production of immature top growth.

At or near maturity bluegrass has elaborated the greatest abundance of feed and at the same time can be grazed heavily, without the injurious "after effects" in the form of a depressed subsequent growth. This invariably occurs when a vegetative and succulent condition is maintained in bluegrass and many other plants, through continuous removals of immature top growth. Such treatment tends to exhaust the supply of reserve foods which are essential for the proper maintenance of growth in the subterranean parts and the continued productivity of the top growth. Sweet clover and winter rye, or any other supplementary pasture plants which produce temporarily and economically abundant early spring pasturage, will make possible the avoidance of heavy grazing of bluegrass and other permanent pasture plants at very early premature stages of growth. Such over-grazing has been a primary cause of the failure of many fertile bluegrass pastures to yield satisfactory returns.

ESTABLISHING SWEET CLOVER IN BLUEGRASS PASTURES

Another manner in which sweet clover promises to become an important aid in the improvement of permanent bluegrass pastures is based on its ability to become established and to grow vigorously on bluegrass sod without plowing or any form of mechanical preparation of a seedbed. For three years (1925, 1926, and 1927) sweet clover has been successfully seeded on an old bluegrass sod on the Miami silt loam of the Experiment Station farm at Madison, Wis-

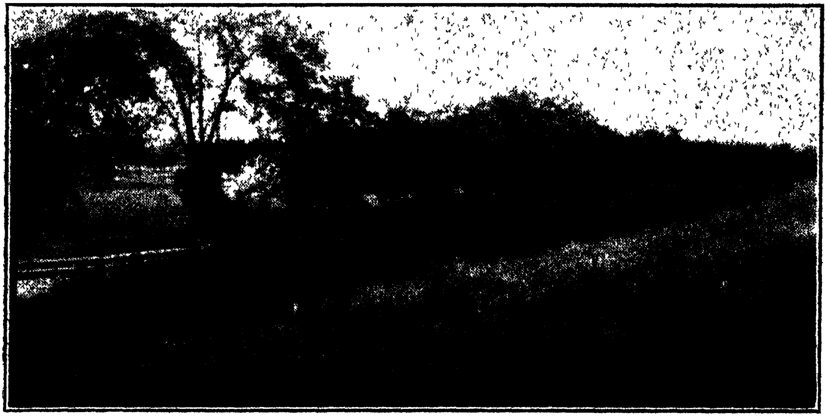

FIG. 1.—Second year's growth of sweet clover in an old bluegrass pasture. This plat of sweet clover was seeded on frozen ground on March 9, 1925, after burning the accumulation of old ungrazed bluegrass from previous years. No cultivation was applied to this sod, either before or after seeding the sweet clover. Alsike clover seeded in the adjacent plat (right) at the same time and under the same conditions failed to become established in the bluegrass. Photo taken June 29, 1926.

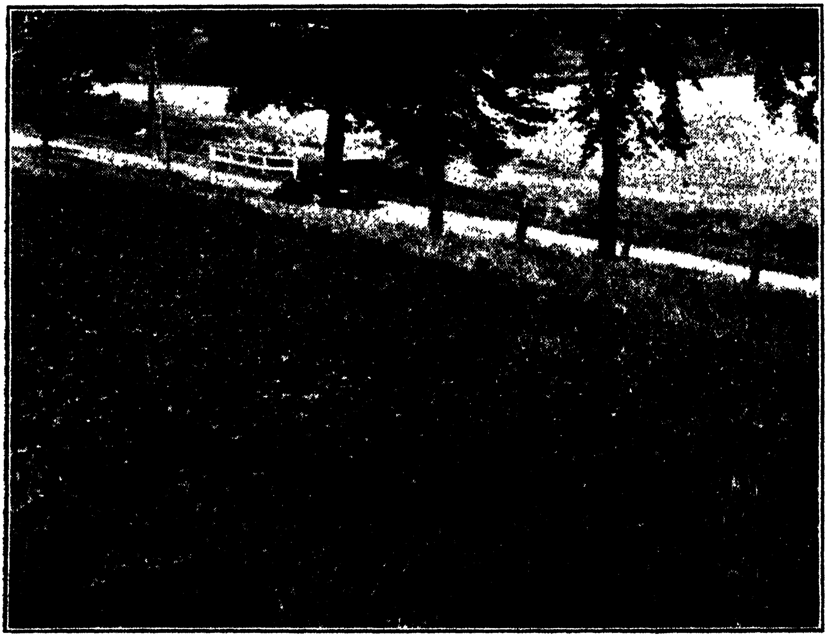

FIG. 2.—Spring growth of sweet clover in bluegrass. This photo is of the same plat as shown in Fig. 1, but was taken on May 28, 1926, from the opposite end. The thin stand of sweet clover (foreground) sown where the old bluegrass was not burned is plainly evident in contrast to the much thicker growth (back ground) where the old grass was burned before seeding the sweet clover.

consin. In these experiments, scarified and inoculated common biennial white blossom sweet clover seed was sown on top of frozen ground during the latter part of that period between winter and spring (in March or the forepart of April) when much alternate freezing and thawing of the soil surface occurs. This seems to be essential for the proper covering of the seed.

The first experiment was begun in 1925. On March 9, while the soil was still frozen, an accumulation of dry bluegrass occasioned by the fact that this bluegrass pasture was not grazed in 1924, was burned. The fire was extinguished along a certain line and common biennial white blossom sweet clover, red clover (*Trifolium pratense*), alsike clover (*Trifolium hybridum*), white clover (*Trifolium repens*), and alfalfa (*Medicago sativa*) were seeded separately in plats which included both the burned and unburned areas of the bluegrass sod. The sweet clover, alfalfa, and red clover were all sown at the rate of 32 pounds per acre with seed with a germination of 90% or more. The alsike and white clover were sown at the rate of 16 pounds an acre using seed with similar germination.

In spite of very dry weather in April and May, a thick stand of sweet clover developed on the burned area. By autumn (1925), it was fully 1 foot in height. On the unburned sod where the accumulation of old grass was not removed, only a few plants of sweet clover became established. The alfalfa, red clover, alsike, and white clover were not conspicuous and the relatively few plants which had esestablished themselves, in competition with the bluegrass, manifested a weak growth in contrast to the vigorous development of the sweet clover. These plats were not pastured or cut in 1925.

In 1926, sweet clover was the only legume which made a prominent appearance in the bluegrass. It was thick and vigorous. All other clovers and alfalfa were so thin in stand and grew so slowly in competition with the bluegrass that their yields were negligible. The sweet clover grew to a height of 3½ feet at maturity. The yields, as taken just before blossoming on part of the plat, are given in Table 1.

On the burned area of the bluegrass sod the sweet clover gave a yield of 4,497 pounds an acre of oven-dried hay just before blossoming on June 24, 1926, and the bluegrass growing with it yielded 1,347 pounds an acre, making a total of 5,844 pounds of dry feed an acre. On an adjacent plat where white clover (*Trifolium repens*) had been seeded and where only a few plants of this clover were in evidence, the bluegrass yielded 2,100 pounds an acre. While the yield of bluegrass was depressed by the heavy growth of sweet clover,

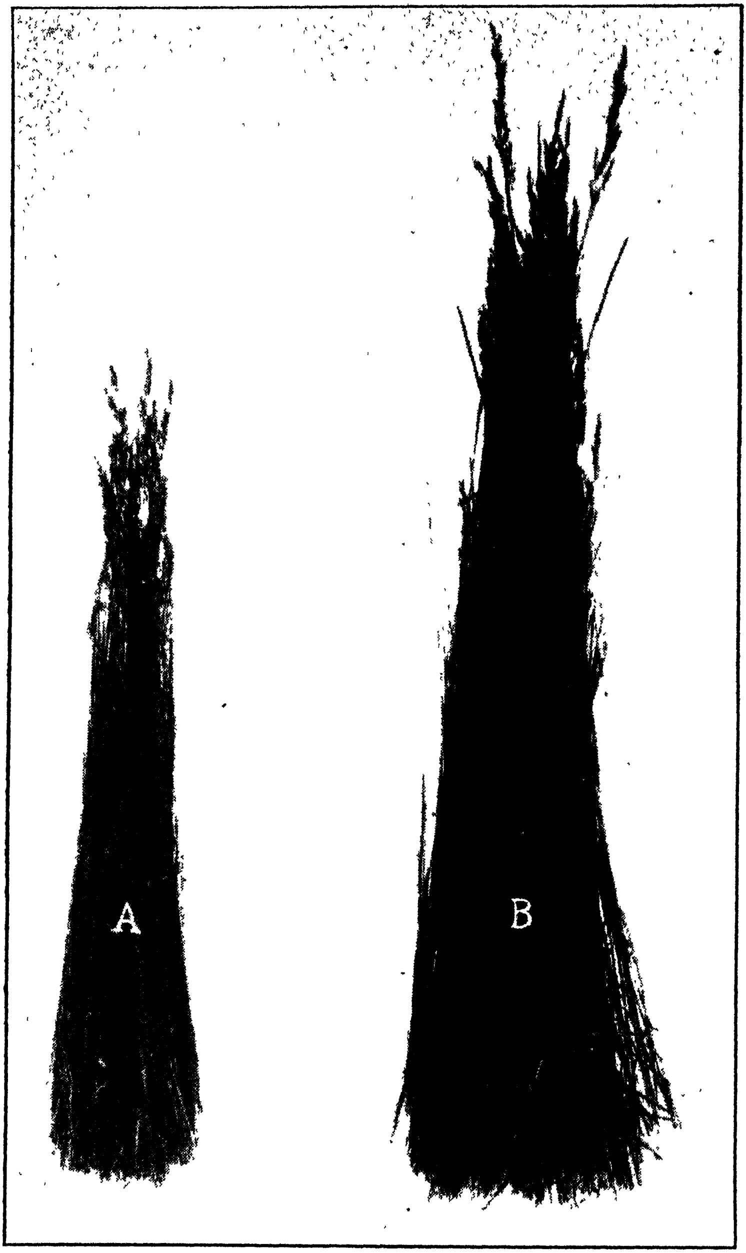

FIG. 3.—Sweet clover improves growth of bluegrass.

The presence of a thick stand of sweet clover during 1925 and 1926 in bluegrass as shown in Fig. 1 had a pronounced effect on the subsequent growth of this pasture grass in 1927, as shown by a comparison of samples A and B. These were from 1 square foot of sod in adjacent plats where sweet clover was (B) and was not (A) grown. Photo taken June 8, 1927.

the combined yield of the sweet clover and bluegrass was almost three times that of the bluegrass in which no sweet clover grew.

TABLE 1.—*Yields of sweet clover and bluegrass and of bluegrass alone.*

Treatment of plats	Treatment of bluegrass	Yields of oven-dried hay in pounds per acre on June 24, 1926		
		Sweet clover	Bluegrass	Total
Sweet clover sown at the rate of 32 pounds an acre on frozen bluegrass sod March 9, 1925	Large accumulations of old grass burned on March 9, 1925	4,497	1,347	5,844
No sweet clover sown[a]	Large accumulations of old grass burned on March 9, 1925	None	2,100	2,100

[a] This plat was seeded with 16 pounds of white clover (*Trifolium repens*) seed an acre, but due to severe drought, only a few plants became established and the yields were negligible.

No yields were taken at this time of the very thin stand of sweet clover in the bluegrass which had not been burned nor of the inconsequential growth of other legumes which were sown on the burned and unburned bluegrass sod. The fact, however, that burning the old grass in the early spring had a very depressing effect on the subsequent growth of bluegrass, as previously reported by the writer,[3] indicates that the decrease in competition of the bluegrass favored the establishment of a much thicker and productive stand of sweet clover on the burned area.

The sweet clover and bluegrass were not cut nor pastured in 1925 or 1926, except such areas as were used to determine yields. The mature growth of sweet clover was not removed until in the spring of 1927, when the dead plants were pulled and taken from the plats. On June 17, 1927, the bluegrass on the plat which had grown sweet clover in 1925 and 1926 yielded 3,638 pounds of oven-dried hay an acre, compared with only 1,174 pounds from the adjacent plat of bluegrass on which no sweet clover had been previously grown in the bluegrass. The growth of sweet clover in this bluegrass for two years, without grazing, trebled the yields. No doubt, the soil was deficient in nitrogen, otherwise such a marked improvement in yield might not have occurred.

The question naturally arises as to the possibility of growing sweet clover in competition with bluegrass after such marked improvement in soil fertility has occurred. In this plat, the abundance of sweet clover seed produced and shed on the plat in 1926 failed to establish a stand in 1927, except for a few scattered plants. Apparently, the bluegrass, stimulated by the absence of grazing in 1925 and 1926 and through the addition of nitrogen to the soil by the sweet clover during these two years, grew so vigorously that the abundantly self-seeded sweet clover of 1926, probably scarified by winter exposure, was not able to establish itself in 1927. What results may have occurred had the sweet clover and bluegrass been grazed during 1926, as would have been true in actual practice, and then reseeded with scarified seed in early spring of 1927, only future work will determine. Parenthetically, it should be mentioned that in these trials no data were obtained in reference to the relative value of scarified, unscarified, and unhulled sweet clover seed for seeding on bluegrass pastures, nor was any evidence secured as to the most effective time for sowing such seed.

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[3] GRABER, L. F. Injury from burning off old grass on established bluegrass pastures. Jour. Amer. Soc. Agron., 18:815–819. 1926.

INJURY FROM GRAZING SEEDLING SWEET CLOVER PLANTS

In 1926, sweet clover was again sown on frozen ground in two plats of bluegrass, the old and new growth of which had been burned off on May 11, 1925. Part of each of these plats was grazed continuously in 1925 and 1926 and part was not grazed during these two years. Scarified seed of the common biennial white sweet clover was used. One plat was sown at the rate of 30 pounds an acre and an adjacent plat at the rate of 10 pounds an acre. The sweet clover seed was sown by hand on frozen bluegrass sod March 28, 1926.

It will be noted by reference to Table 2 that the sweet clover was practically a failure in the portion of the plat where the bluegrass was grazed in 1926. The few plants which survived such grazing yielded only 245 pounds of dry sweet clover hay an acre on June 17, 1927. On the remainder of this plat where no grazing was permitted

TABLE 2.—*Yields obtained with seeding sweet clover (Melilotus alba) in a bluegrass pasture on March 28, 1926, with heavy and light rates of seeding and with and without grazing during 1926.*

Grazing treatments of bluegrass and sweet clover during 1926	Rate of seeding in pounds per acre	Yields of oven-dried hay in pounds per acre: October 22, 1926: Sweet clover	October 22, 1926: Bluegrass	October 22, 1926: Total	June 17, 1927: Sweet clover	June 17, 1927: Bluegrass	June 17, 1927: Total
Not grazed[a]	30	962	1,383	2,345	2,506	1,024	3,530
Grazed heavily[b]	30	48	529	577	245	870	1,115
Not grazed[a]	10	493	1,960	2,453	694	1,118	1,812
Grazed heavily[b]	10	None	373	373	112	768	880

[a] Accumulation of old grass was burned off May 11, 1925, but this plat was not grazed or cut in 1925, 1926, or 1927.

[b] Accumulation of old grass was burned off May 11, 1925. This plat was grazed lightly in 1925, heavily in 1926, and not grazed or cut in 1927.

in 1926, a thick, vigorous stand of sweet clover occurred in the bluegrass and a yield of 2,506 pounds of dry hay was obtained two weeks before the sweet clover began to bloom. This comparison is for the plats seeded at the rate of 30 pounds of sweet clover an acre, but somewhat similar results are also evident where 10 pounds an acre of seed were sown.

The avoidance of pasturing for one year is a very important consideration in the establishment of successful stands of sweet clover in permanent bluegrass pastures. If the seedling plants of sweet clover growing in competition with established bluegrass are constantly grazed, a high mortality occurs and those plants which survive have slight opportunity to manufacture and store organic food reserves necessary for root growth, for resistance to winter injury, and for productivity the following year. The increase from the combined yields of sweet clover and bluegrass and the subsequent improvement in the fertility of the soil justify, from a practical viewpoint, the losses sustained by the absence of grazing for one year to permit sweet clover to become established in bluegrass. Pastures infested with tall-growing weeds would probably require clipping to prevent seeding and to aid in holding such weeds in check during the first year's growth of sweet clover.

Under the conditions of this experiment, seeding sweet clover in bluegrass at the rate of 30 pounds an acre gave much larger yields (Table 2) than seeding 10 pounds an acre. This seems logical. An established bluegrass sod probably offers much more competition to the development of seedling sweet clover plants than a nurse crop sown simultaneously with sweet clover on cultivated and prepared land. It would appear that a much higher percentage of the viable seed would produce plants able to survive the climatic hazards of the growing season and the competition with other plants when sown on plowed and cultivated soils than when sown in established bluegrass pastures. It is believed by the writer, although evidence is not sufficient to support a final conclusion, that heavier rates of seeding will be necessary for the establishment of sweet clover in old bluegrass pastures without cultivation.

In 1927 sweet clover was again seeded on frozen bluegrass sod and successfully established as indicated by the present (August) thickness and vigor of growth. No yield data on this seeding will be available until later.

GENERAL DISCUSSION

It is not the intention of the writer to give the impression that seeding sweet clover on old bluegrass pastures may become a uni-

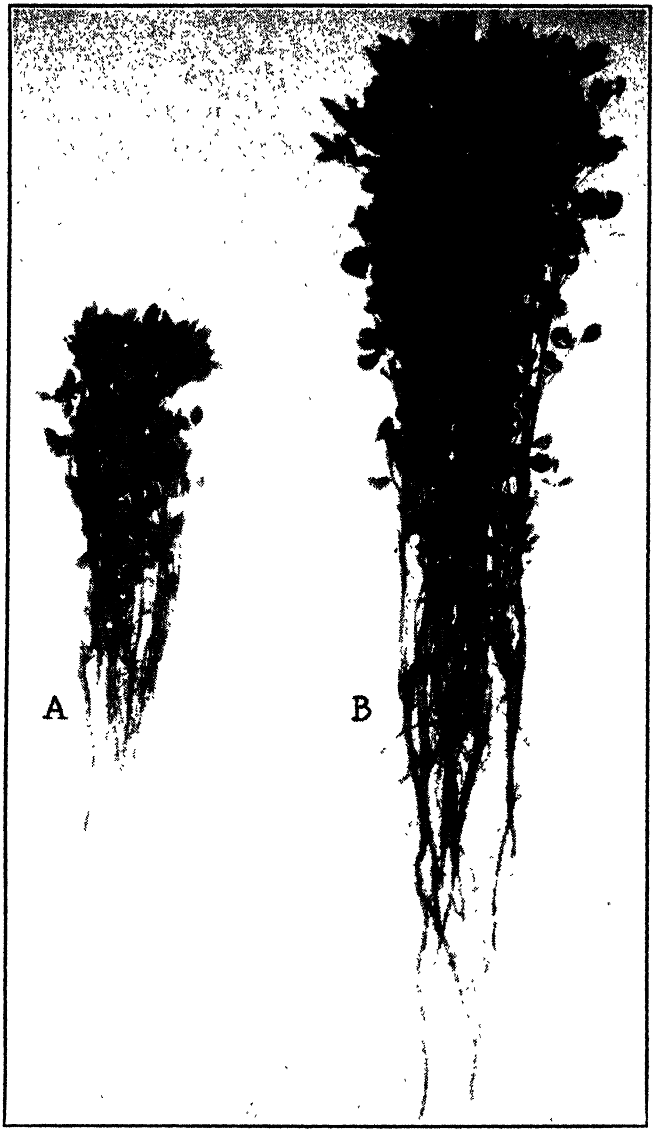

FIG. 4.— Effects of grazing seedling plants of sweet clover on their second year's growth.

Part of a plat of sweet clover seeded on bluegrass sod March 28, 1926, was grazed heavily that year, while the remainder was not grazed. Sample A shows the amount of root and top growth of sweet clover on June 8, 1927, taken from the portion of the plat grazed in 1926, while sample B represents the growth of plants from the ungrazed portion. The dry weights of the roots (upper 5 inches) and tops of 20 plants were as follows.

	Roots	Tops
Sample A	6 grams	25 grams
Sample B	25 grams	126 grams

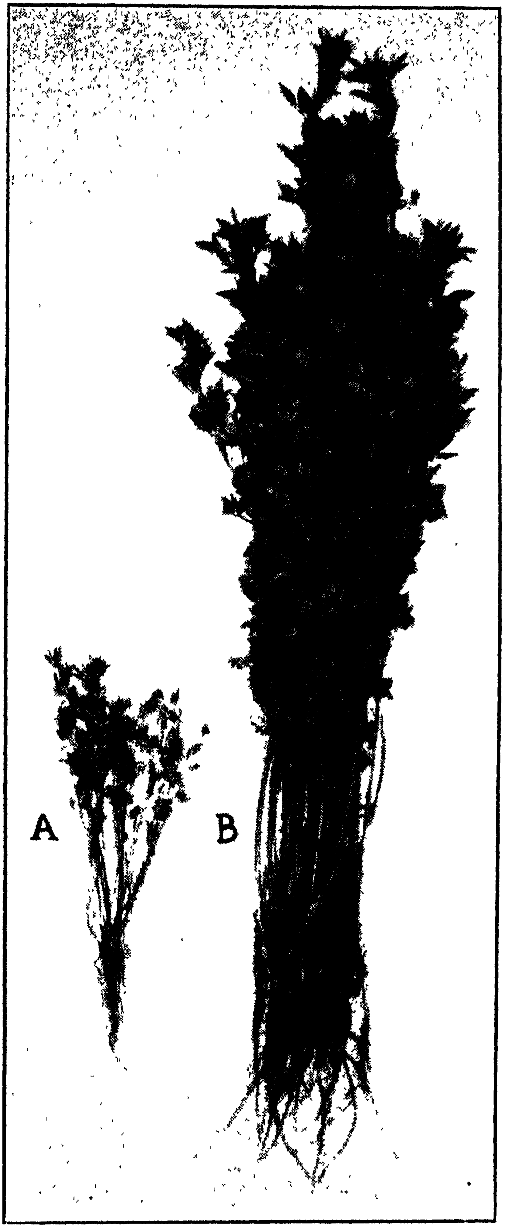

FIG. 5.—Growth of alfalfa and sweet clover seeded on bluegrass sod. Alfalfa (A) and sweet clover (B) were seeded on adjacent plats of frozen bluegrass sod on March 28, 1926. The relative amount of root and top growth in the blue grass is shown by 20 average plants of the alfalfa (A) with a total dry weight of only 8 grams and 20 average plants of sweet clover (B) weighing 173 grams after drying. Photo taken June 16, 1927.

versally successful practice. This will only be determined by widespread experimentation and field trials which will give much more information than is now available. The proper time and rate of seeding for scarified and unhulled seed need to be determined for the many widely varying conditions of soil and climate under which it may be feasible to establish sweet clover in permanent bluegrass pastures.

It can be said with certainty that success will rarely obtain where heavy grazing is practiced on the pasture the first year sweet clover is sown and no data are necessary to assert that failure will result where soils are seriously lacking in lime and phosphorus. It is probable that on soils rich in nitrogen the heavy growths of bluegrass will hinder and make much more difficult the development of sweet clover, even though lime and the mineral elements of fertility, so favorable to the growth of sweet clover, are plentiful in such soils. Where an abundance of old grass remains on the pasture from accumulations of previous years, sweet clover is less easily established, unless such growths are burned off before the sweet clover is sown. The burning depresses the growth of the grasses and permits the seed to come in contact with the soil.

It appears that the most optimum conditions for the growth of sweet clover in permanent pastures obtain when the competition of the grasses is reduced by burning accumulations of old grass, or by previous overgrazing, or by deficiencies of nitrogen in soils which have naturally or by application an abundant supply of lime and mineral elements of fertility. Pastures where improvement is most badly needed are those in which sweet clover can be most readily established.

In practice, the growth of sweet clover in bluegrass would require a division of the permanent pasture into two parts which could be seeded and grazed in alternate years. This would eliminate the grazing of the seedling sweet clover plants and permit them to become well started in the bluegrass. Pastures which have become unproductive, due to years of premature overgrazing, would be benefited by having an opportunity to develop maturity of the grasses, while the sweet clover was becoming established. This should greatly aid bluegrass in building up a reserve supply of organic foods for the renewal of growth in the subterranean parts and the improvement of subsequent top growth. Along with such internal improvement in plant growth, the addition of nitrogen to the soil by the sweet clover should do much to increase the subsequent productivity of the bluegrass.

Pastures most seriously in need of improvement, owing to deficiencies of nitrogen in the soil, or due to deficiencies in productivity from premature overgrazing, are those in which sweet clover will probably be most readily grown and where the greatest benefits from its growth are apt to occur.

It is recognized by the writer that evidence for or against the use of sweet clover for the improvement of permanent bluegrass pastures, either as a supplementary pasture plant, or by the growth of sweet clover in established bluegrass pastures, is so limited that invasions into the realm of speculation are, at present, more or less hazardous. Much more specific evidence on the numerous phases of this problem than is now available will be required before definite recommendations can be made. In Wisconsin, several practical trials are being conducted through county agents and with individual farmers. Many of these have given promising results, as well as valuable information. Manifestly, the opportunity of utilizing sweet clover for the improvement of unproductive permanent pastures offers a rich field for the investigator of those numerous unsolved and neglected problems of tame pastures.

SUMMARY

1. Sweet clover, winter rye, and other plants producing abundant early spring growth which may be utilized for supplementary pasture make possible a "deferred" system of management for permanent bluegrass which will aid in the elimination of the injurious practice of heavy and close premature grazing.

2. For three years sweet clover was successfully established in an old bluegrass pasture. While the growth of sweet clover (second year) depressed the yield of bluegrass, the combined yield of the sweet clover and the bluegrass in which it grew was nearly three times that obtained from a plat of bluegrass in which no sweet clover was sown.

3. Scarified and inoculated sweet clover seed was sown at heavy rates on frozen bluegrass sod in the latter part of that period of alternate freezing and thawing of the soil surface which occurs in Wisconsin during March and April and which, on the heavier soils, seems to cover the seed effectively without any form of seedbed preparation or cultivation.

4. Sweet clover seeded on bluegrass will not become well established in pastures which are continuously and heavily grazed during the year of seeding. Constant grazing of the seedling plants of sweet clover results in a high mortality and very weak growth of the surviving plants the following year. The storage of organic foods

and the root development during the first year's growth of sweet clover has an important bearing on its productivity the following year.

5. Should the use of sweet clover as a companion crop in bluegrass pastures become generally practicable, it will necessitate the division of such pastures and grazing the sweet clover on each division only, in years which alternate with the year of the seeding of this biennial legume. The absence of grazing for one year while sweet clover is becoming successfully established in bluegrass is justified by the resulting increase in yields and subsequent fertility.

6. The growth of sweet clover in bluegrass, without grazing in 1925 and 1926, trebled the yields of this pasture grass in 1927, as compared with the yields from an adjacent plat of bluegrass in which no sweet clover had been grown. Growing sweet clover in poor pastures when such lands are deficient in nitrogen offers great opportunities for soil improvement.

7. Factors which tend to depress the growth of bluegrass, such as previous close and heavy premature grazing or burning of the accumulations of old grass, or deficiencies in the nitrogen content of the soil, otherwise rich in mineral elements of fertility, greatly aid the sweet clover in becoming thickly established in permanent bluegrass pastures.

8. Sweet clover was the only legume seeded on bluegrass sod in 1925 which successfully survived subsequent summer drought. The few surviving plants of alfalfa, of red, and of alsike clover failed to grow satisfactorily in competition with the bluegrass in 1926.

9. The growth of sweet clover is generally most easily established in permanent pastures which are unproductive or most in need of improvement, but this is particularly true where such soils contain naturally, or by application, an abundance of lime and phosphorus.

RELATION OF FERTILITY TO WATER REQUIREMENT OF PLANTS[1]

W. L. POWERS[2]

In earlier reports (1, 2, 3, 4, 5),[3] the relation between the concentration of the soil solution and the water requirement of plants has been established. The purpose of the present article is to report field studies for determining the value of application of this factor for decreasing the irrigation requirement and increasing profits under irrigation farming.

SULFUR FERTILIZER TRIAL

A field fertilizer experiment was arranged on the University of California Irrigation Experiment Field near Delhi. This trial was designed to test laboratory and greenhouse results as applied to field conditions, to provide a field source of samples for laboratory studies from treated soils, to measure the value of sulfur in increased crop yields, and to determine the effect of fertilizer applied on irrigation requirement and water requirement. Ten one-sixth acre plats in Range 4 and four one-fifth acre plats in Range 3 of the experiment field were used for this trial and treatments were given as indicated in Table 1.

All plats received 36 inches irrigation and nearly 3 inches of rainfall during the growing season. Soil moisture samples were taken in the field to a depth of 6 feet at the beginning of the season and at the time of the last cutting, February 4 and October 21, respectively. The gain or loss in soil moisture during the season, together with rainfall and irrigation water, made a total depth of water used of from 37 73 to 40.87 inches, and made it possible to calculate the units of water consumed per unit dry matter yielded. Moisture determinations were made on all plat crops at each cutting

The dry weights given in Table 1 would make the increase about 20% less than if yields were expressed as cured hay weights. Sulfur and sulfates increased the yields substantially, the gain running from 1 to 2 tons an acre over the yields from untreated plats. The maximum yield was secured with calcium sulfate. Calcium alone in amounts equivalent to that obtained from calcium sulfate caused

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[1] Contribution from the Soils Department, Oregon Agricultural Experiment Station, Corvallis, Ore. Received for publication August 17, 1927.

[2] Chief in Soils. The writer wishes to acknowledge the kindness of Prof. Frank Adams, of the University of California Agricultural Experiment Station, for the privilege of using field plats and of Mr. Frank Davis for assistance in the treatment and care of field plats near Delhi, Calif.

[3] Reference by number is to "Literature Cited," p. 1011.

TABLE 1.—*Summary of results of fertilizer experiments, Irrigation Experiment Field, Delhi, Caifornia, 1924–25.*

Block	Check	Treatment in pounds per acre	Total dry weight pounds of alfalfa per acre, 1924	Pounds of water to 1 pound of dry alfalfa, 1924	Total dry weight pounds of alfalfa per acre, 1925	Pounds of water to 1 pound of dry alfalfa 1925
IV	1	None	6,210.0	1,504.0	6,720.0	1,429.0
IV	2	Sulfur, 100	10,860.0	844.0	8,010.0	1,227.0
IV	3	Gypsum, 600	13,230.0	686.0	9,360.0	1,065.0
IV	4	Calcium, 180[a] Sulfur, 100	10,800.0	862.0	9,210.0	1,065.0
IV	5	None	9,690.0	923.0	7,920.0	1,232.0
IV	6	$(NH_4)_2SO_4$, 500	12,720.0	715.0	11,280.0	846.0
IV	7	K_2SO_4, 600	12,450.0	719.0	12,480.0	777.0
IV	8	Calcium, 100	11,310.0	819.0	8,970.0	1,078.0
IV	9	Super phos., 750	11,610.0	783.0	10,710.0	924.0
IV	10	None	11,160.0	795.0	10,200.0	983.0
III	1	None	9,800.0	872.0	8,675.0	1,138.0
III	2	Sulfur, 100	12,350.0	692.0	10,200.0	946.0
III	3	Sulfur, 200	12,500.0	688.0	11,425.0	850.0
III	4	None	9,950.0	888.0	10,455.0	942.0

[a] Calcium added to plat 4 in fresh water-slaked form equivalent to that applied to plat 3 in sulfate.

a moderate increase in yield. The increase in yield from sulfur alone was a little less than that secured with calcium sulfate and slightly less than that secured with potassium sulfate. There was little advantage during the first season from supplying sulfur at the rate of 200 pounds an acre as compared with the 100-pound application. Treated plats gave larger dry matter yields, with lower water requirement per unit dry matter produced. All plats treated with sulfur or sulfate produced alfalfa with deep green color which made a vigorous growth throughout the season. Alfalfa on untreated plats had a yellowish color and made less rapid or vigorous growth. Calcium alone caused a lighter green color, especially early and late in the season. Superphosphate failed to maintain more vigorous growth than untreated plats late in the season. Application of 200 pounds an acre of sulfur did not produce materially more alfalfa than was obtained from a 100-pound treatment. There was some evidence that calcium was obtained more readily in the presence of sulfate.

Soil moisture samples taken at the beginning and end of each growth period, together with measurements of rainfall and irrigation, made it possible to calculate the total water used by the crop on each plat. Crop moisture determinations were also made to permit calculation of water requirement per pound of dry matter. Generally, the water requirement for each unit of dry matter was lower where dry matter yield was increased by use of any fertilizer. In such cases the explanation is offered that when the concentration of the soil solution is increased as a result of fertilizer application, then less molecules of water or the ions thereof are absorbed by the growing plant per ion of necessary nutrient taken or unit carbohydrate assimilated. The uniform amount of irrigation applied to all plats at Delhi tended to decrease differences in water consumed. More striking differences in yield per unit of water have been secured in the Oregon fertilizer experiments where remarkable increases have been secured from use of sulfur in certain cases.

In the irrigation field at the Oregon Experiment Station rotation and manure used with supplemental irrigation have cut the water cost per pound of white beans in half as a 12-year average, while in Goose Lake Valley sulfur applications have doubled the alfalfa yield and the dry matter produced per unit of irrigation. Where use of sulfur or other treatment increases the average alfalfa yield of a valley as much as a ton an acre a season at small expense, it has a beneficial effect on the productive land values Results of some of the long-time sulfur trials in Oregon will indicate the economic importance of such practices.

EFFECT OF SULFUR AND SULFATE ON TYPICAL OREGON SOILS

The yields secured with and without sulfur from several typical Oregon soils are summarized in Table 2. Sulfur has been used on Antelope clay adobe soil and on Willamette silty clay loam for 12 years. Generally the application in field trials has been 100 pounds every three or four years, or once each rotation where the land is not a permanent meadow. At the Oregon Experiment station the old fertilizer experiment on Willamette silty clay loam involves a rotation of grain, clover, and corn, with sulfur applied on two certain plats each three years. The application in this particular experiment has been 320 pounds each three years and sulfur has thus been applied to these sulfured plats four times during the last 12 years. The heaviest application (400 pounds per acre) at Medford Experiment Field on Antelope clay adobe has been repeated twice, so that a total of 1200 pounds of sulfur has been applied to certain plats there.

The Umatilla sandy soil receives large amounts of irrigation water carrying 2 or 3 pounds of sulfur per acre foot, amounting to 10 to 15 pounds of sulfur per acre per season. Only slight increases from sulfur are realized on that field.

Yakima sandy loam in the Klamath Basin and Deschutes sandy loam in Central Oregon give increases of 1 to 2 tons of alfalfa a season

TABLE 2.—*Summary of field trials with sulfur for alfalfa on typical Oregon soils.*

Soil type	Locality	Length of trial in years	Yield in tons per acre		Gain in tons per acre
			Untreated	Sulfured	
Umatilla medium sand	Proj. Exp. Farm	8	2.93	4.02	1.10
Yakima sandy loam	Klamath Project	8	5.0	3.5	1.5
Deschutes sandy loam	Redmond Exp. Field	10	2.55	4.35	1.8
Union loam	East Oregon Exp. Sta.	7	6.41	6.96	0.55
Antelope clay adobe	Medford Exp. Field	12	0.57	2.67	2.10
Carlton silt loam	N. Albany (clover)	4^a	197^b	280^b	83^b
Willamette silty clay loam	Oregon Exp. Sta. (clover)	12	8.04^c	10.32^c	2.28^c

[a] Yield expressed in pounds of seed per acre.

[b] Green weight.

[c] Clover seed in bushels.

from sulfur applications. Both are arid, slightly alkaline soils liberally supplied with total calcium and having only a moderate amount of potassium ion in their soil solutions. The supply of bases in the soil solution is apparently improved by the sulfur applications. The amount of sulfate in the solutions of these soils is not large. Potassium salts pay on potatoes in Deschutes Valley and sulfur is found to treble the potassium concentration in the soil solution. The recovery of sulfate concentration in this soil after depletion by a crop is slow (6).

Union loam is slightly acid in reaction and on this experiment field calcium sulfate gives better response than does sulfur. One effect of sulfur or sulfate may be to increase the amount of available potassium. Sulfur appears to cause unfavorably acid soil

Antelope clay adobe soil of the Medford Experiment Field is neutral in reaction and contains a calcareous subsoil. The only substantial difference found in the soil water extract is twice the amount of iron in solution as a result of sulfur application. It is possible that this is an important factor in connection with the results from the use of sulfur on that field. The supply of sulfate in the soil is not large, however, and sulfofication is slow. Before the growing season winter precipitation causes some leaching and interferes with sulfofication. The available sulfate may be limited early in the season when alfalfa makes its heaviest demands for this nutrient. Alfalfa is almost a failure without sulfur on this land and with sulfur very substantial crops are produced.

Carlton silt loam is a "red hill" soil common throughout the foothills, particularly on the west side of the Willamette Valley, and the total sulfur and the sulfate content of this soil are both rather low.

The amount of potassium in the soil solution was also found to be low early in May when the soil was sampled for displacement. The plats at this time were supporting a growth of winter grain. These foot hill soils are often low in water-soluble phosphate and calcium. They are distinctly acid. Sulfur increases yields probably due to various effects on this hill group of soils.

Willamette silty clay loam has a relatively good supply of total sulfur and strong sulfofying power. Except early in the spring, there should be considerable sulfate in this soil solution. This soil is productive and well supplied with organic matter. There is some indication of calcium, and possibly potassium, being liberated by the sulfur treatment. Crop increase due to sulfur applications has been slight. It appears that the combined form, calcium sulfate, can be most safely applied to these humid soils. Light spring applications of gypsum are customary for legume crops grown on these latter two soil types.

Sulfur oxidation products may greatly increase the supply of reactive calcium; or improve the reaction of arid soils for alfalfa nutrition, or on certain soils and at certain seasons may result in a more favorable sulfate concentration for legumes (7). In general, the effect of sulfur that will be paramount may depend upon the characteristics of the soil at hand, its reaction, physical condition, chemical composition, or micro-organic flora. The increased yield from this fertilizer has generally been secured at a reduced water cost.

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THE SOIL SOLUTION AS A NUTRIENT MEDIUM FOR PLANTS[1]

W. L. Powers[2]

The first percolate collected from lysimeter tanks at the beginning of the rainy season at the Oregon Experiment Station has been found to be similar in composition to the displaced soil solution from the same soil type and has been used for growing barley seedlings in water cultures in the greenhouse with interesting results.

The soil employed in these studies is Willamette silt loam, a valley-filling soil with mature profile developed under an annual rainfall of 42 inches and having in the surface 2,000,000 pounds a total of 1660 pounds of nitrogen, 3440 pounds of phosphate, 37,000 pounds of potassium, 260 pounds of sulfur, and 22,400 pounds of calcium. The surface soil has a pH value of about 5.5 and contains 0.332% calcium and 0.030% magnesium in the form of exchangeable base.

The similarity in composition between the displaced soil solution and the percolate collected at the beginning of the rainy season is shown in Table 1.

TABLE 1.—*Chemical composition in p.p.m. of soil solution vs. percolate from untreated lysimeter, Willamette silt loam.*

	N	Ca	SO_4	PO_4	K
Displaced soil solution	Trace	45.0	17.0	4.0	11.0
Percolate	21.8	36.5	11.5	1.3	11.4

A very similar amount of the various important ions is found in the displaced soil solution and in the percolate with the single exception of nitrate. The lack of nitrate in the displaced soil solution is due to the samples having been taken from land supporting a young growth of grain which at the time was 8 inches tall and had probably removed most of the available nitrate. It seems that the first portions of percolate from drainage bins approximate the composition of the soil solution where the dry season is broken by gentle rains which gradually moisten the soil in the lysimeters and cause swelling of the soil mass so that the soil solution is gradually displaced without channeling or appreciable dilution with rain water. The average amount and composition of percolation from different untreated and treated lysimeters are reported elsewhere.[3]

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[1] Contribution from the Soils Department of the Oregon Agricultural Experiment Station, Corvallis, Ore. Released with the approval of the Director. Received for publication August 17, 1927.

[2] Chief in Soils. The writer wishes to acknowledge the assistance of W. M. Higby in laboratory work connected with this report.

[3] HIGBY, W. M. Lysimeter studies. Soil Sci., 24:51–56. 1927.

A preliminary study was made in which the essential nutrients were added to the lysimeter water. Solutions of salts containing only one of the essential ions, such as calcium, nitrogen, sulfur, phosphorus, or potassium, were prepared by adding the ions as calcium chloride, sodium nitrate, sodium sulfate, sodium acid phosphate, or potassium chloride, respectively. These single salt solutions were added to the lysimeter water in stoneware jars and barley seedlings were grown on them for a 30-day period with the reaction controlled. Increases caused by supplying a single essential nutrient ion were unimportant.

A second series of cultures were grown in which the essential elements were supplied in the following combinations:

1. Lysimeter water unchanged.
2. Lysimeter water changed or renewed each three days.
3. Lysimeter water plus potassium nitrate.
4. Lysimeter water plus calcium sulfate.
5. Lysimeter water plus magnesium acid phosphate.
6. Lysimeter water plus potassium nitrate and calcium sulfate.
7. Lysimeter water plus potassium nitrate and magnesium acid phosphate
8. Lysimeter water plus magnesium acid phosphate and calcium sulfate.
9. "Complete" culture solution.

Barley plants were grown in perforations on paraffined veneer covers on stoneware jars of the above solutions having 3.2 liter capacity, 24 plants being grown per jar. Iron tartrate solution was added to all solutions periodically to supply iron. Each combination was run in duplicate.

Different sets of cultures to which two or more essential ions were applied in favorable combinations gave very marked results over the control for certain combinations, as shown in Fig. 1 and Table 2. Potassium nitrate added to the lysimeter water produced a growth

TABLE 2.—*Weight of seedlings grown on lysimeter water and reinforced with nutrients.*

Pot No.	Treatment	Average yield in grams	
		Tops	Roots
1 & 11	Percolate unchanged	1.718	1.616
2 & 12	Percolate changed	2.262	2.300
3 & 13	Culture solution	6.361	3.173
4 & 14	Percolate+KNO_3	4.245	2.390
5 & 15	Percolate+$CaSO_4$	1.304	1.603
6 & 16	Percolate+$MgHPO_4$	0.396	1.262
7 & 17	Percolate+KNO_3+$CaSO_4$	3.123	5.057
8 & 18	Percolate+KNO_3+$MgHPO_4$	2.229	1.315
9 & 19	Percolate+$MgHPO_4$+$CaSO_4$	0.527	0.836

nearly equal to the yield from a complete artificial culture solution. With potassium nitrate and calcium nitrate added to the lysimeter water, the yield was second to that of the potassium nitrate. The plants grown on the solution fortified with magnesium phosphate apparently suffered from magnesium injury.

These experiments indicate that the percolate from lysimeter tanks at the beginning of the rainy season affords a means of securing a solution that approximates the composition of the soil solution in quantities sufficient for culture experiments. The importance of proper pairing of essential ions to physiological availability, as suggested by Gericke[4], is shown from these studies. It appears that for barley plants the essential ions, especially nitrate and potassium, are of insufficient concentration or amount in the percolate or in the soil solution to support the best growth without replenishment and that these ions are best taken up by the plant in association with each other. From similar studies, it appears that calcium is taken by the plant very well in association with sulfate and that phosphate may be taken in association with magnesium. Evidence has been obtained that late in the growing period nitrate may be supplied advantageously in association with calcium.

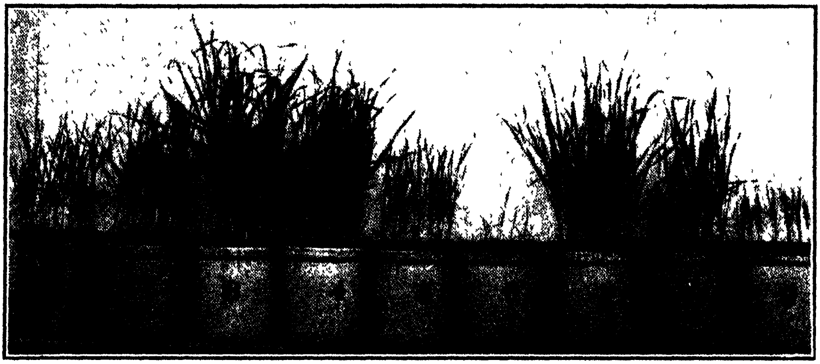

FIG. 1.—Barley plants grown on drainage water to which nutrients have been added.

1, drainage water unchanged; 2, drainage water changed; 3, "complete" solution; 4, KNO_3 added; 5, $CaSO_4$ added; 6, $MgHPO_4$ added; 7, $CaSO_4$ and KNO_3 added; 8, KNO_3 and $MgHPO_4$ added; 9, $CaSO_4$ and $MgHPO_4$ added.

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A SIMPLIFIED CELL FOR DETERMINING THE ELECTRODIALYSABLE BASE CONTENT OF SOILS AND PERMUTITS[1]

Richard Bradfield[2]

INTRODUCTION

The exchangeable cation content of a soil is now considered one of its most important characteristics. Pedologists are finding information regarding exchangeable bases of great value in studying the development and classification of soils. Soil physicists and reclamation engineers are requiring the same information for the solution of their problems. The practical soil chemist is striving to find relationships between exchange reactions and crop response to soil amendments and fertilizers in the field. Because of this wide-spread interest in the subject, considerable attention has been devoted to investigations of methods of determining these exchangeable cations. Practically all of the methods proposed for routine use have been based on prolonged leaching with different neutral salt solutions, or with dilute acids.

There are several rather serious objections to these methods. (1) They are slow and tedious, expecially with heavy soils. (2) The true exchange reactions are frequently complicated with direct solution effects. (3) They do not give good results with soils containing calcium carbonate. (4) The analysis of the filtrate is made difficult because of the presence of the large amount of salt used as extractant.

Because of these objections to the neutral salt methods, an investigation has been made of another method which has proved quite satisfactory on all of the soils studied. The principal involved is quite simple. The exchangeable bases can be readily replaced by the hydrogen ion of weak acids. It is to be expected, therefore, that they would be displaced to a certain extent by the hydrogen ions in water. The slight extent of the replacement, or hydrolysis in this case, being due entirely to the low concentration of hydrogen ions present. If the calcium-saturated exchange complex is represented by CaX, the reaction would be: $CaX + 2HOH = H_2X + Ca(OH)_2$. This reaction is forced to the right by increasing the concentration of the H^+ in the acid extraction methods. It is quite possible that the same result might be accomplished by removing the soluble

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[1] Contribution from the Department of Soils, Agricultural Experiment Station, University of Missouri, Columbia, Mo. Received for publication August 28, 1927.

[2] Associate Professor of Soils.

product of hydrolysis, in this case the $Ca(OH)_2$. Since the exchange complex is of colloidal and the $Ca(OH)_2$ of crystalloidal dimensions, this separation can be readily effected by means of electrodialysis.[3]

Experiments with the ordinary three-compartment electrodialysis cell show that in most normal soils of the humid region the amount of electrodialyzable anions is very small in comparison with the amount of cations. The exchangeable cations are tied up with alumino-silicate and humate anions which are of colloidal dimensions. If, therefore, a separation of the crystalloidal from the colloidal anions is not desired, a two-compartment cell can be used for the separation of the bases, the anode being placed in the same compartment as the soil sample. This arrangement eliminates the resistance of one membrane and enables one to place the electrodes much closer together, and consequently accelerates the removal of the bases.

TECHNIC

The type of cell now used in this laboratory is shown assembled in Fig. 1. A 2- to 10-gram sample of air-dry soil is placed inside the alundum extraction thimble which serves as the diaphragm. The R.A. 84 dense extraction thimble, 32x127 mm, which is carried regularly by most chemical supply houses, has proved the most satisfactory diaphragm yet tried. Parchment thimbles become brittle after being used a few times. Collodion bags are easily ruptured, while unglazed porcelain tubes are slower than the alundum ones. The latter are easily cleaned and can be used for a long time. The thimble containing the soil sample is placed in the Pyrex cell which is about the same length as the thimble and about 4.5 cm in diameter. A side arm, 3 to 4 mm in diameter, is sealed on about 2 cm from the top and a similar tube attached to the bottom. The cathode is made of perforated nickel and is in the form of a cylinder about 5 to 6 cm high and just large enough in diameter to slip over the outside of the of the alundum thimble easily. A three-hole No. 6 rubber stopper, which supports the perforated platinum foil anode, a siphon from the constant level water reservoir, and a short thistle tube or funnel complete the cell proper.

Water is introduced into the alundum thimble and is maintained

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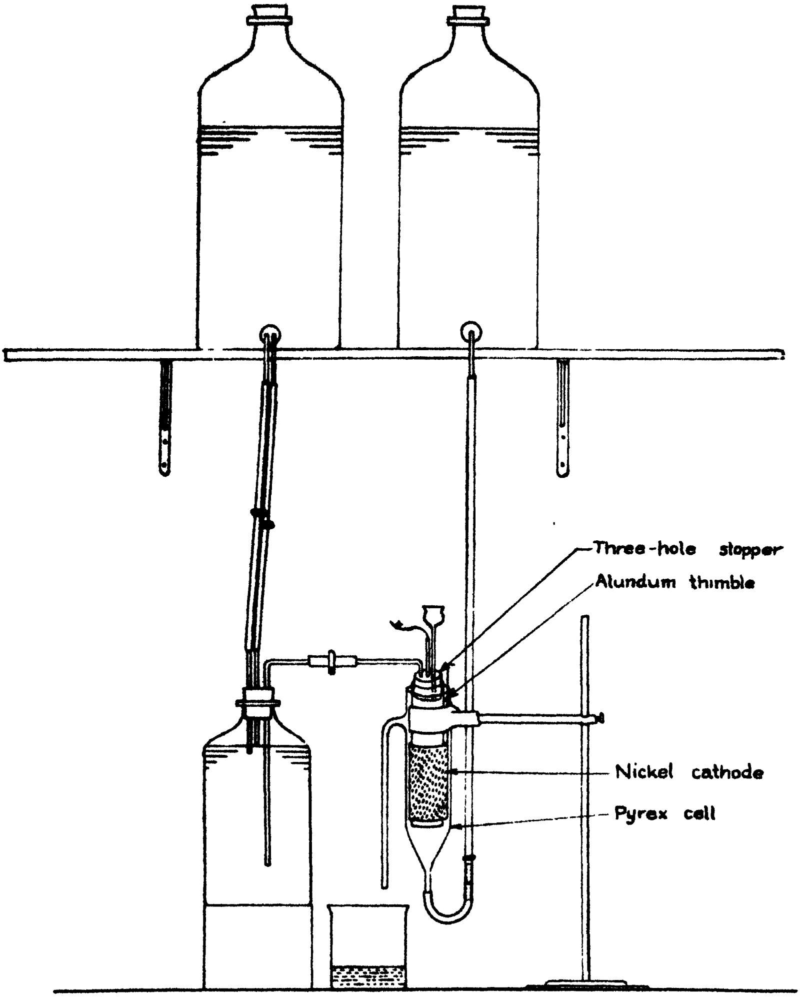
[3] The application of electrodialysis to soils is discussed more fully in the following papers:

MATTSON, S. Electrodialysis of the colloidal soil material and the exchangeable bases. Jour. Agr. Res., 33:553-567. 1926.

BRADFIELD, R. The use of electrodialysis in physico-chemical investigations of soils. Presented before First International Congress of Soil Science. Washington, D. C. 1927.



Two-compartment continuous-flow type of electrodialysis cell

FIG. 1.

at a constant level by means of the siphon. The space between the thimble and the Pyrex cell is filled with water by opening the screw clamp at the bottom of the latter. When a potential of 50 to 200 volts D.C. is applied at the electrodes the exchangeable cations are drawn to the cathode and there form their respective hydroxides. In order to avoid overheating and to keep down possible side reactions, especially oxidation of the organic matter at the anode, it is well to connect an adjustable rheostat in series with the cell and by its use to keep the current under 0.5 ampere. With the alundum diaphragm there is, with a few rare exceptions, an endosmotic flow of water toward the cathode which flows out the side arm and continuously removes the catholyte which is caught in a liter beaker. After four to eight hours the dialysate will be found to be practically free from bases. During this period from 500 to 1000 cc of dialysate is usually obtained. Some $Mg(OH)_2$, $MgCO_3$, and $CaCO_3$ may be precipitated in the cathode chamber and may cling to the Pyrex cell, cathode, and the outside of the alundum thimble. For that reason, as soon as the current is shut off the latter should be removed and carefully washed with the distilled water, using a rubber policeman to loosen any adhering precipitate. These washings are added to the dialysate. The cathode and the Pyrex cell are both placed in the beaker containing the dialysate and a 50 to 100% excess of standard acid, HCl or H_2SO_4, added. The beaker is then placed on a hot plate and boiled to expel any CO_2 absorbed and to neutralize any precipitate adhering to the cell or electrode. The latter are then removed, rinsed with distilled water, and the excess acid titrated with a standard base. The difference in titer between the acid added and that of the dialysate plus the acid gives the total amount of exchangeable bases expressed in terms of chemical equivalents. The amount of Ca and Mg present may be determined by the usual methods and the amounts of Na plus K obtained by difference. In case a direct determination of the alkali metals is desired the titration may be made with NH_4OH, the salt formed volatilized, and the Na and K determined by the usual methods.

With a few of the soils studied, especially those rich in $CaCO_3$ or gypsum, an endosmotic flow of water toward the anode has been observed during the first few minutes of the dialysis. When this occurs, which is very rarely if the current is kept under 0.5 ampere by means of a suitable resistance, the screw clamp on the siphon is closed to prevent the passage of part of the soil into the constant-level bottle. The water is then forced into the thistle tube which serves merely as a temporary reservoir. As soon as the siphon is closed the clamp on the tube attached to the bottom of the cell is opened and the products of electrodialysis washed out by a stream of water from the bottle on the right in Fig. 1. After a few minutes normal endosmosis toward the cathode will be restored. The reversal of the charge on the membrane is apparently due to an unusually high concentration of divalent cations in its pores.

After an alundum thimble has been used for a few experiments it will be found to be partly clogged by a deposit of iron and aluminum hydroxides. This can be removed by boiling in 3 to 5% HCl. The excess acid is removed by drawing distilled water through the thimble by means of a suction pump. Electrodialysis may be used to remove the last traces of acid, but for most routine work this is unnecessary unless an analysis of the anions is to be made. The new thimbles usually contain some electrodialysable base and, for that reason, should be given the acid treatment before being used.

EXPERIMENTAL

The exchangeable base and electrodialysable base content of a soil are identical only in the case of soils practically free from ordinary salts. This applies to most non-calcareous soils of the humid region. In the case of calcareous or saline soils, the dialysate contains the exchangeable bases plus bases present as carbonate, sulfate, nitrate, etc. In such cases the soil must be analysed for these anions and the amount found subtracted from the total electrodialysable bases in order to obtain the amount of exchangeable bases. A comparison of the exchangeable calcium content of a few soils, as determined by the ordinary neutral normal NH_4Cl extraction method and by electrodialysis, is given in Table 1.

TABLE 1.—*The exchangeable calcium content of a series of soils as determined by NH_4Cl extraction and by electrodialysis.*

Soil	Method NH_4Cl	Electrodialysis
Putnam colloid	15.3	13.5
Putnam surface soil	5.6	6.8
Putnam subsoil	12.6	11.5
Chillicothe clay	26.0	26.2
Muck	44.7	44.0
Susquehanna clay (saturated with Ca)	35.3	34.8

The data given in Table 2 illustrate the agreement which may be expected between duplicate samples when electrodialyzed.

TABLE 2.—*Total electrodialyzable bases in a Cherokee silt loam horizon.*

Horizon	Depth in inches	Base content[a] Sample 1	Sample 2	Average
Surface A_1	0–8	6.6	6.1	6.35
Subsurface A_2	9–15	4.8	4.8	4.80
Subsoil B	18–26	24.8	24.5	24.6
Substratum C[b]	32–48	64.4	63.6	64.0

[a] Expressed as milliequivalents per 100 grams of air-dry soil.

[b] This sample contained considerable gypsum.

The soil remaining in the extraction thimble after electrodialysis is saturated with hydrogen. If it is free from crystalloidal anions this sample may be used for determining the saturation capacity by any of the reliable methods for determining exchangeable hydrogen. In case a mechanical analysis of the soil is desired this sample is well suited for the purpose because it is free from the strongly coagulating divalent cations, and it may be saturated with NH_4 or Na by the addition of the proper amount of hydroxide.

SUMMARY

The advantages of electrodialysis over the neutral salt extraction methods for determining the exchangeable base content of soils are as follows: (1) quicker, especially with heavy soils; (2) direct solvent effects are minimized as only water is added to the soil; (3) carbonates and gypsum are quantitatively removed; and (4) analysis of the dialysate is simplified as only the bases obtained from the soil are present and since these bases are in the form of hydroxides, the total amount present may be easily determined by titration with a standard acid.

A simple, inexpensive cell, well suited for routine work, is described and typical results obtained with it are cited.

EFFECT OF PERICARP INJURY ON MOISTURE ABSORPTION, FUNGUS ATTACK, AND VITALITY OF CORN[1]

H. W. ALBERTS[2]

INTRODUCTION

The pericarp of corn kernels is frequently injured by bruising, by mice, or by shelling. Before corn is fully mature, the crowns of the kernels are easily bruised when handled. In regions where the crop is grown primarily for silage, seed corn is often harvested when the moisture content ranges from 25 to 40%. In the practice of selecting seed corn previous to maturity the crowns of kernels are subject to injury where the corn is handled in sacks or in baskets.

Mice gnaw the crowns of kernels where seed corn is stored on the ear, and if the percentage of horny endosperm is high, injury is usually limited to the removal of pericarp and only a small percentage of endosperm. However, if the endosperm contains a relatively large amount of soft starch, mice feed upon it until they reach the harder portions.

Shelling the grain from the ears may cause injury to the tips of kernels by tearing off a portion of the pericarp. This type of injury is especially noticeable when the moisture content of corn is high at the time of shelling. Some strains are very susceptible to such injury.

Various investigators have shown some of the effects of pericarp injury upon disease resistance, germination, growth, and yield of corn. Myers (5)[3] found that where the seed coat is broken, saprophytic fungi invade the endosperm. Hurd (4) found that wheat kernels otherwise immune become susceptible to attack by saprophytes when injured. Hurd (3) also showed that with uninjured grain germination tests made in soil in the laboratory gave the same results as those made at the same time in blotters, while with injured grains the two methods gave dissimilar results. In blotters all grains which produced both roots and plumules were counted as viable, while in the soil seedlings from injured grains never reached the surface. Brown (1, 2) found that fewer of the broken kernels germinate than those of the unbroken ones. Injured kernels produced weaker seedlings than those that were uninjured. The general height of plants at maturity did not differ materially. The yield per plant from broken kernels was consistently less than that from unbroken kernels.

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[1] Contribution from the Departments of Botany and Agronomy, University of Illinois, Urbana, Illinois. The work upon which this paper is based was done under the direction of Dr. Charles F. Hottes and Dr. W. L. Burlison to whom the writer is indebted for helpful suggestions and constructive criticisms. Received for publication Sept. 16, 1927.

[2] Formerly Instructor in Agronomy, University of Wisconsin, Madison, Wisc. Now Director of Experiment Stations, United States Department of Agriculture, Sitka, Alaska.

[3] Reference by number is to "Literature Cited," p. 1029.

The present investigation was undertaken to study the relative value for seed purposes of uninjured corn and that which was injured by bruising, by mice, or by shelling. A comparison of moisture absorption, fungus attack, and vitality of the embryo was made between uninjured and injured corn.

MATERIALS AND METHODS

In these studies, a portion of several ears of Reid Yellow Dent corn containing 11.0% moisture (total weight basis) was mutilated by removing the crown pericarp with a sharp knife to imitate mouse injury (Fig. 1). The corn was then shelled, and 126.5 grams placed in each of four wire baskets 14 cm high and 4 cm in diameter. Two baskets, one containing mutilated and the other uninjured kernels, were suspended in ½-gallon fruit jars each containing 250 cc of sulfuric acid. The other two baskets, containing the mutilated and the uninjured kernels, were suspended in similar jars each containing 250 cc of water. The respective baskets above water and acid were interchanged daily for the first five days. After the fifth day they were left unchanged until the seventh day when final readings were made.

EFFECT OF PERICARP INJURY ON MOISTURE ABSORPTION AND MOISTURE LOSS IN CORN

The results shown in Table 1 indicate that mutilated kernels lose more moisture in dry air than the uninjured kernels, and that they absorb more moisture in moist air than do the uninjured kernels.

When the readings were taken at the end of the first day, mutilated sample No. 2 had lost 1.26% of its original weight, while uninjured sample No. 1 had lost only 0.79%. On the second day, with both samples above water, mutilated sample No. 2increased 3.24% of its original weight and uninjured sample No.1 increased 3.63% of its original weight.

The uninjured sample above water on the second day contained more moisture than the mutilated sample, but it must be borne in mind that mutilated sample No. 2 had lost 1.26% compared with 0.79% loss for the uninjured sample. Thus, it was found that while the uninjured sample showed a greater gain in percentage above the original weight the actual amount of water absorbed was less than that absorbed during the same period and under the same conditions by the mutilated sample.

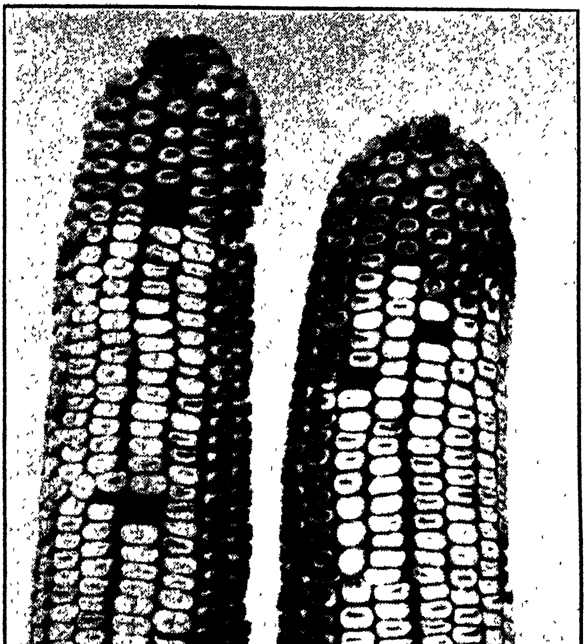

FIG. 1.—Ears of corn showing a portion of kernels having the crown pericarp removed with a sharp knife.

1. Ear stored in open air. Endosperm shows cracking. 2. Ear stored in an unheated room. Lower left portion of the ear shows crown pericarp removed by mouse injury.

TABLE 1.—*Gain and loss in percentage of corn suspended alternately in atmospheres of high and low relative humidity.*

Sample No.	Description and treatment	Deviation from original weight at end of 1 day %	2 days %	3 days %	4 days %	5 days %	7 days %
1	Uninjured corn—suspended first over sulfuric acid	—0.79[a]	+3.63	+1.02	+5.21	+1.58	+7.19
2	Mutilated corn—suspended first over sulfuric acid	—1.26[a]	+3.24	+0.79	+4.42	+0.39	+6.80
3	Uninjured corn—suspended first over water	+3.71	+0.97	+4.18	+0.87	+4.58	0
4	Mutilated corn—suspended first over water	+4.60	+0.55	+5.06	+0.79	+4.74	—0.63[a]

[a]Below original weight.

Under the conditions of the experiment the total daily moisture variations were greater for mutilated than for uninjured corn. Table 2 shows the extreme daily variations for each lot of corn. These figures were obtained by taking the algebraic differences between the percentages recorded on any one day in Table 1 and those of the previous day.

A comparison of the extreme daily fluctuations in the mutilated and the uninjured samples shows that moisture absorption and moisture loss were generally greater in mutilated than in uninjured corn.

Effect of pericarp injury was in evidence also in corn stored on the ear. Mutilated corn stored indoors for a period of nearly six months retained its original appearance, while that which was stored outside

TABLE 2.—*Extreme daily variations in weight of corn.*

Sample No.	Description and treatment	Extreme daily variation First day %	Second day %	Third day %	Fourth day %	Fifth day %	Seventh day %
1	Uninjured corn—suspended first over sulfuric acid	0.79	4.42	2.61	4.19	3.63	5.61
2	Mutilated corn—suspended first over sulfuric acid	1.26	4.50	2.45	3.63	4.03	6.41
3	Uninjured corn—suspended first over water	3.71	2.74	3.21	3.31	3.71	4.58
4	Mutilated corn—suspended first over water	4.60	4.05	4.51	4.27	3.95	5.37

showed a cracking and crumbling of the endosperm due to repeated expansion and contraction resulting from exposure to wide atmospheric fluctuations in relative humidity and temperature. At the close of the experiment the mutilated kernels were distorted as shown in Fig. 1.

EFFECT OF PERICARP INJURY ON FUNGUS ATTACK OF CORN

Mutilated kernels were attacked more readily by fungi than uninjured kernels. Studies on fungus attack were made on corn treated in the following manner: First, crown pericarp of the kernels was bruised or broken on portions of the ear; second, corn was shelled before it was dry; third, corn was shelled after it was dry but the moisture content was increased after shelling; and, fourth, crown pericarp of the kernels was removed prior to planting.

Kernels having a bruised or broken pericarp and a high moisture content were subjected to fungus invasion. About 10 bushels of dent corn obtained directly from the field and containing from 30 to 40% moisture (total weight basis) were used in this test. Some of the kernels on the ears were bruised so severely in handling that the crown pericarp was broken. The corn was hung on wire hangers so that no two ears were in contact and stored in a poorly ventilated room at a temperature of 25° C (77°F). Fungi developed first on the kernels with broken pericarps and spread to the uninjured kernels from the injured areas as centers of infection. After a period of six days a profuse fungus growth had developed on, and adjacent to, the bruised portions of the ears. No fungus growth appeared on the uninjured kernels not adjacent to the bruised areas.

Fungi developed on parts of kernels from which the tip pericarp had been broken in the shelling process. Corn containing 32% moisture (total weight basis) was shelled and placed in sealed jars to prevent further loss of moisture. In nearly every instance, fungus growth appeared first on the portion of the kernel where a part of the tip pericarp had been removed.

In the test where the moisture content in the corn was reduced to 11.5% before shelling and then raised after shelling, there was no severe pericarp injury. The test was made, however, to determine on what portion of the shelled kernel fungi made their appearance first. The shelled corn was therefore suspended in wire baskets above water in a sealed jar at a temperature of 20° C for 17 days. Observations were made at various intervals and it was found that in nearly all instances fungi appeared first at the place where the kernel had been attached to the cob. When an apparent growth was visible, the moisture content of the corn had increased to about 24%.

Mutilated kernels were readily attacked by soil fungi. Kernels with the crown pericarp removed, and also uninjured kernels, were planted in soil. Upon examination of the germinating kernels it was found that saprophytic fungi—mostly pinkish in color—had invaded the endosperm where the pericarp had been removed. No visible fungus attack could be seen on the uninjured kernels. Fungus infection appeared on nearly all the mesocotyls of the seedlings from mutilated kernels, while only a small percentage of seedlings from uninjured kernels showed mesocotyl infection.

EFFECT OF PERICARP INJURY ON THE VIABILITY OF CORN

Pericarp injury reduced the germination, the sprout weight, and the seedling growth of corn. Germination tests were made by placing 10 kernels in duplicate from each lot on a sawdust-lime germinator kept in a room at a temperature of 26° C for nine days. Average sprout weights at the time of reading the germination test were obtained by weighing the plumules and roots after the kernels had been removed and dividing the weight by the total number of kernels that germinated. A study of seedling growth was also made on plants growing in soil in the greenhouse.

Germination tests indicated that the removal of crown pericarp reduced the viability of corn stored out of doors, but had no effect upon the viability of corn stored in an unheated room. The average viability of kernels from mutilated corn stored out of doors was 42.5% as compared with an average viability of 100% for mutilated corn stored in an unheated room. The results of the test are shown in Table 3.

A comparison of the mutilated with the uninjured kernels from the lots stored out of doors shows 57.5% of the injured kernels dead as compared with 2.5% dead for the uninjured. Both mutilated and uninjured kernels stored in an unheated room showed a viability of 100%.

Under both conditions of storage, the weight of the sprouts produced by kernels where the crown pericarp had been removed was less than that produced by uninjured kernels. The average sprout weight of the viable kernels from the uninjured portions of the ears stored out of doors was 1.22 grams, while the average sprout weight from the mutilated kernels was 0.70 gram, or a decrease of 42%. A similar reduction in sprout weight was found when mutilated kernels were stored in an unheated room, but the percentage of viable kernels was higher than where corn was stored out of doors.

Sprouts from kernels where the crown pericarp had been removed emerged slowly and their development was retarded. (See Fig. 2.)

TABLE 3.—*Viability and sprout weight of uninjured and mutilated corn under different conditions of storage.*

Stored out of doors on the side of a building								Stored in an unheated room							
Kernels uninjured				Kernels with crown pericarp removed				Kernels uninjured				Kernels with crown pericarp removed			
Lot No.	Dead kernels	Viable kernels	Average sprout weight of viable kernels	Lot No.	Dead kernels	Viable kernels	Average sprout weight of viable kernels	Lot No.	Dead kernels	Viable kernels	Average sprout weight of viable kernels	Lot No.	Dead kernels	Viable kernels	Average sprout weight of viable kernels
	%	%	*Grams*		%	%	*Grams*		%	%	*Grams*		%	%	*Grams*
1	10	90	1.02	5	90	10	0.46	9	0	100	1.12	13	0	100	0.34
2	0	100	1.33	6	70	30	0.53	10	0	100	1.51	14	0	100	0.67
3	0	100	1.18	7	0	100	0.94	11	0	100	1.4	15	0	100	0.75
4	0	100	1.36	8	70	30	0.88	12	0	100	1.37	16	0	100	1.0
Average	2.5	97.5	1.22		57.5	42.5	0.70		0	100	1.35		0	100	0.69

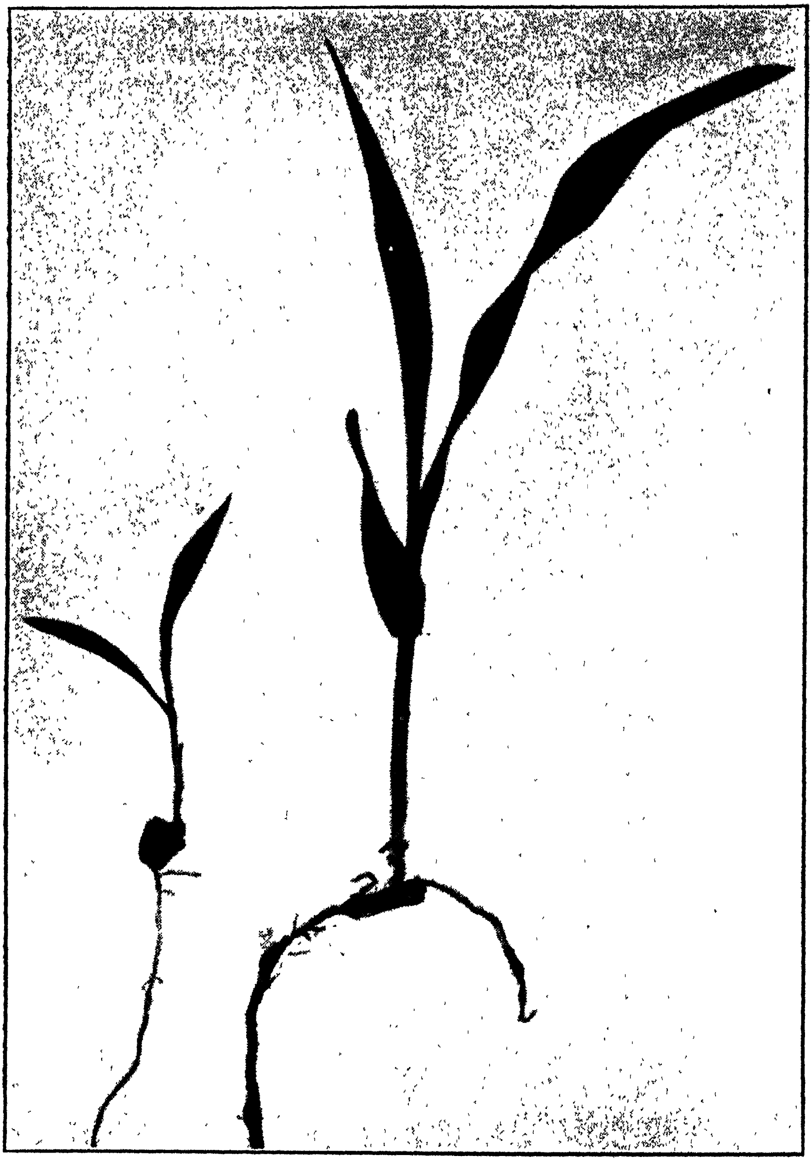

Fig. 2.—Seedlings from mutilated and uninjured kernels. Left, kernel from which crown pericarp was removed. Right, uninjured kernel.

When the average height of the seedlings from mutilated kernels was 5 cm, that of the seedlings from the uninjured kernels was 12 cm.

At this stage the mutilated kernels had nearly the same shape and size they had when planted, while the uninjured kernels that produced vigorous seedlings were shrunken and reduced in size.

DISCUSSION

Seed corn injury caused by handling or by the gnawing of mice is an important factor in reducing the subsequent growth of the plant. When a portion of the pericarp is broken or removed, the endosperm is exposed to atmospheric fluctuations of moisture and, as a consequence, the stabilizing function of this portion of the seed coat is lost. Enzymes secreted by the epithelial cells of the scutellum diffuse through the endosperm and the products of their action readily become available to fungi when the pericarp is broken.

Invading organisms utilize the hydrolized starch for their metabolism and secrete enzymes of their own which cause a rapid decomposition of the endosperm.

The weakened seedling resulting from pericarp injury must depend upon the soil for its entire supply of food materials at an early stage. Growth of the weakened seedling is slow and the mesocotyl is subject to attack by facultative parasitic fungi which further check the development of the seedling.

It is evident, therefore, that mechanically injured corn is undesirable for seed purposes. While it may show 100% viability on the germinator, it cannot produce as vigorous seedlings as uninjured seed, even though the latter may have a slightly lower viability.

SUMMARY

1. Moisture was absorbed more rapidly in moist air and was withdrawn more rapidly in dry air by injured kernels than by uninjured kernels.
2. Saprophytic fungi invaded the endosperm where the pericarp was broken or removed.
3. Pericarp injury did not reduce the viability when corn was stored in a place where there was little fluctuation of atmospheric moisture.
4. The sprout weight and subsequent growth and vitality of the seedlings were less from the injured than from the uninjured kernels.
5. Corn injured by bruising or by the gnawing of mice is of little value for seed purposes.

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REGISTRATION OF VARIETIES AND STRAINS OF OATS, II[1]

T. R. STANTON, H. H. LOVE, AND E. E. DOWN[2]

Since publishing the first list of registered varieties and strains of oats in 1926 (8),[3] the following additional new and improved sorts have been approved for registration. As was true of those registered previously, these do not represent definite botanical varieties in all cases, but rather physiological strains of certain standard varieties.

They are as follows:

Group and Varietal Name	Registration Number
Spring Oats	
Early Red:	
Frazier	65
Kanota	66
Midseason Red:	
Nortex	67
Midseason Yellow:	
Keystone	68
Patterson	69
Midseason White:	
Wolverine	70
Worthy	71

Approval of registration is based on the description and record of these varieties, which are summarized here for the convenience and benefit of those not familiar with them.

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[1] Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Department of Agriculture, and the American Society of Agronomy. Received for publication October 15, 1927.

[2] Agronomist in Charge of Oat Investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture; Professor of Plant Breeding, Cornell University, Ithaca, N. Y., and Collaborator, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture; and Assistant Professor and Research Associate in Farm Crops, Michigan Agricultural College, East Lansing, Mich., respectively. Members of 1927 Subcommittee of the American Society of Agronomy for the Registration of Oat Varieties.

[3] Reference by number is to "Literature Cited," p. 1036.

FRAZIER—Reg. No. 65

Frazier (C. I. No. 2381) was originated as a pure-line selection from a variety known as Frazier Red Rustproof, which was obtained by the Texas Agricultural Experiment Station from the farm of Tom Frazier, Morgan, Tex., in 1911. The original plant selection (Texas Station No. 765-16-1), later named Frazier in honor of the deceased father of Tom Frazier, was made in 1918 at Substation No. 6, Denton, Tex., by A. H. Leidigh, and was subsequently developed by C. H. McDowell and P. B. Dunkle. Application for its registration was made in the name of Texas Agricultural Experiment Station, Substation No. 6. Frazier is an early red oat of the Fulghum type. It differs primarily from Fulghum in that both kernels of the spikelet usually bear awns. The superior characters of Frazier are early maturity, high yield, and resistance to smut. It has been tested for six years in replicated nursery rows and field plats at Denton. The annual and average acre yields in bushels obtained in the six years, 1921 to 1926, inclusive, for Frazier as compared with Fulghum, are as follows:

	Yield in Bushels Per Acre						
Variety	1921	1922	1923	1924	1925	1926	Average
Frazier (new)	39.9	53.8	81.4	130.9	52.4	45.6	67.3
Fulghum (standard)	39.9	46.3	71.7	124.3	42.1	48.8	62.2

Frazier has been distributed to a number of farmers in northeastern Texas, especially in the Denton section. For further information on the Frazier oat see Jackson (2).

KANOTA—Reg. No. 66

Kanota (C. I. No. 839) was introduced into Kansas and was tested and distributed by the Kansas Agricultural Experiment Station. The stock of seed was obtained in 1916 by the Kansas Station from the Robert Nicholson Seed Co., Dallas, Tex. The preliminary tests were made under the direction of S. C. Salmon at Manhattan, Kans. It was first distributed to farmers of Kansas in 1919 under the name of Kansas Fulghum, but later was named Kanota. Application for its registration was made by S. C. Salmon and John H. Parker. Kanota is an early red oat of the Fulghum type. It is similar to the original Fulghum in plant and kernel characters. The superior characters of Kanota are high yield, high test weight, earliness, and smut resistance. Kanota has been tested for 11 years in nursery rows and field plats on experiment stations and for 8 years on farms in Kansas, the latter tests being made under the direction of H. H. Laude. The annual and average acre yields in bushels of Kanota as compared with Fulghum at Manhattan for the nine years, 1916 to 1924, inclusive, in cereal nursery and field plats and compared with Red Rustproof in cooperative tests with farmers, are shown on page 1033.

It was estimated that Kanota was grown on about 1,000,000 acres in Kansas in 1926. For further information on Kanota see Salmon and Parker (4) and Stanton (7).

Variety	Yield in bushels per acre											
	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	Average
	Nursery Yields											
Kanota (new)	104.7	93.8	63.4	59.6	28.2	34.1	16.1	55.5	41.2	——	——	55.2
Fulghum, Kansas No. 5181 (standard)	45.9	97.4	59.8	66.9	28.8	41.3	14.5	58.3	30.7	——	——	49.3
	Plat Yields											
Kanota (new)	——	58.5	30.1	54.3	45.5	42.9	59.7	41.2	33.6	47.2	39.6	45.3
Fulghum, Kansas No. 6084 (standard)	——	65.2	18.8	37.3	35.5	36.0	54.7	46.0	36.0	48.5	41.2	41.9

Yields From Cooperative Tests With Farmers

	1919	1920	1921	1922	1923	1924	1925	1926	Average
No. of tests	7	27	22	25	35	34	27	13	190
Kanota	46.9	42.8	37.5	32.4	39.9	40.0	36.0	48.1	40.5
Red Rustproof	32.4	37.2	26.5	19.8	33.5	23.7	30.0	41.9	30.6
Difference	14.5	5.6	11.0	12.6	6.4	16.3	6.0	6.2	9.9

NORTEX—Reg. No. 67

Nortex (C.I. No. 2382) was originated by the Texas Agricultural Experiment Station at Substation No. 6, Denton, as a pure-line selection from Red Rustproof, Texas Station No. 1118. The plant was isolated in 1920 by A. H. Leidigh, and it was subsequently developed by C. H. McDowell and P. B. Dunkle. The Texas Agricultural Experiment Station, Substation No. 6, applied for its registration. It was first distributed to farmers in 1924. Nortex is an early to midseason red oat, typical of the Red Rustproof type. It is suitable for fall or February seeding. The superior characters of Nortex are high yield, stiff straw, and maturity from one to three days earlier than ordinary Red Rustproof. It has been tested in replicated rod rows and field plats at Denton for six years. The acre yields in bushels obtained in the four-year period from 1923 to 1926, inclusive, as compared with ordinary Red Rustproof, are as follows:

Yield in Bushels Per Acre

Variety	1923	1924	1925	1926	Average
Nortex, Tex. Sta. No. 9235 (new)	94.6	111.6	67.2	104.4	94.5
Red Rustproof, Tex. Sta. No. 1415 (standard)	114.0	105.9	57.7	83.5	90.3

Nortex was sown on approximately 750 acres in the vicinity of Denton in the fall of 1926. For further information on Nortex see Jackson (3).

KEYSTONE—Reg. No. 68

Keystone (C. I. No. 2146) was originated as a pure-line selection (53-11) from a variety known under the name of Japan. The plant selection was made at Pennsylvania State College in 1910 by C. F. Noll. Keystone was first distributed to farmers in southern Pennsylvania in 1921. Keystone is an early to midseason, small-kerneled oat similar to the Green Russian. Its superior characters are high yield, early maturity, and thin hulls. Keystone has been tested by the Pennsylvania State College for 12 years in duplicated field plats with a check of a standard variety every third plat. The annual and average acre yields in bushels of Keystone as compared with Sixty-Day, the standard variety, and also with Cornellian and Victory, in the five years from 1922 to 1926, inclusive, at State College, are as follows:

Yield in Bushels Per Acre

Variety	1922	1923	1924	1925	1926	Average
Keystone (new)	58.7	45.6	82.7	52.0	92.0	66.2
Sixty-Day (standard)	57.5	31.4	57.3	47.2	56.5	50.0
Cornellian	54.8	46.4	76.1	56.8	96.6	66.1
Victory	64.5	48.6	82.4	64.4	78.6	67.7

This variety is now grown on a considerable acreage in southern Pennsylvania, where varieties ripening about one week later than Kherson and Sixty-Day and about one week earlier than Victory are preferable.

PATTERSON—Reg. No. 69

Patterson (C. I. No. 2147) was originated as a pure-line selection (66-11) from a variety grown in Pennsylvania under the name of Japan. The plant was isolated at Pennsylvania State College in 1910 by C. F. Noll. Patterson was distributed to farmers for the first time in the spring of 1920. Patterson is an early to midseason yellow oat similar to Green Russian. Its desirable characters are high yield on farms, early to midseason maturity, and rather thin hull. It has been tested at State College for 12 years in duplicated field plats with a check of a standard variety every third plat. The annual and average acre yields in bushels of the Patterson as compared with Sixty-Day, the check variety, and with Cornellian and Victory at State College, are as follows:

Yield in Bushels Per Acre

Variety	1922	1923	1924	1925	1926	Average
Patterson (new)	53.3	38.9	77.1	63.8	83.5	63.3
Sixty-Day (standard)	57.5	31.6	57.3	47.2	56.5	50.0
Cornellian	54.8	46.4	76.1	56.8	96.6	66.1
Victory	64.5	48.6	82.4	64.4	78.6	67.7

The Patterson has been much more promising in tests throughout the state than at State College.

A comparison of Patterson with Keystone and other varieties in demonstration tests on Pennsylvania farms in 1923, 1924, and 1925, is as follows.

	1923		1924		1925	
Variety	No. of tests	Average gain for Patterson in bushels per acre	No. of tests	Average gain for Patterson in bushels per acre	No. of tests	Average gain for Patterson in bushels per acre
Patterson and Keystone	16	3.7 ± 1.00	38	2.6 ± 0.59	50	4.1 ± 0.66
Patterson and Victory	22	8.3 ± 0.86	45	8.4 ± 0.93	50	0.3 ± 0.81
Patterson and Cornellian	20	2.9 ± 2.00	42	2.1 ± 0.68	49	3.6 ± 0.53
Patterson and Ithacan		.	.	.	39	2.2 ± 0.83
Patterson and local varieties	21	7.4	37	8.5	43	7.0 ± 0.77

Patterson is fairly well distributed over Pennsylvania. Results of tests on farms indicate that it has a wider and more general adaptation in the state than Keystone.

WOLVERINE—Reg. No. 70

Wolverine (C.I. No. 1591) was originated at the Michigan Agricultural Experiment Station, East Lansing, from a plant selection from an unnamed commercial variety. It was selected in 1911 by the late F. A. Spragg, formerly plant breeder of that institution. Application for its registration was made by H. M. Brown. It was first distributed to farmers of Michigan in 1917. Wolverine is a midseason white oat of the Silvermine type. Its superior characters are high yield and stiff straw. It has been tested at East Lansing for eight years in field plats 4 drill rows wide, 7 inches between drills, and 400 feet in length, or in plats 11 drill rows wide, 7 inches between drills, and 300 feet in length. Duplicated plats were used each year. Alleys between plats were 21 inches wide. A standard variety was grown in every fourth or fifth plat as a check. The annual and average acre yields in bushels of Wolverine as compared with Alexander, the standard variety, for the eight-year period from 1914 to 1917, and 1921 to 1924, inclusive, are as follows:

Yield in Bushels Per Acre

Variety	1914	1915	1916	1917	1921	1922	1923	1924	Average
Wolverine (new)	61.6	101.7	50.9	59.4	30.9	33.6	31.8	63.3	54.2
Alexander (standard)	50.6	82.1	53.6	45.5	28.1	30.6	30.3	68.1	48.6

This variety has found great favor through the south central portion of Michigan, and today is grown on a considerable acreage in that area. For further information on Wolverine see Cox (1) and Spragg (5, 6).

WORTHY—Reg. No. 71

Worthy (C.I. No. 1590) was originated at the Michigan Agricultural Experiment Station, East Lansing, as a pure-line selection from an unnamed commerical variety. The individual plant was selected in 1906 by the late F. A. Spragg, formerly plant breeder of that institution. Application for registration of Worthy was made by H. M. Brown. It was first distributed to farmers in 1911. Worthy is a midseason white oat of the Silvermine type. Its superior qualities are high yield, stiff straw, and adaptability for growing on heavy clay soils. Worthy has been tested at East Lansing for nine years in field plats 11 drill rows wide, 7 inches between drills, and 300 feet in length, or in plats 4 drill rows wide, 7 inches between drills, and 400 feet in length. Alleys between plats were 21 inches wide. The varieties were grown in duplicated plats each year. The annual and average acre yields in bushels of the Worthy as compared with Alexander, the standard variety for the nine-year period from 1909 to 1917, inclusive, are as follows:

Yield in Bushels Per Acre

Variety	1909	1910	1911	1912	1913	1914	1915	1916	1917	Average
Worthy (new)	73.1	70.5	72.3	62.6	58.8	52.6	80.4	56.2	44.6	63.5
Alexander (standard)	70.1	75.0	74.0	67.2	51.6	50.6	82.1	53.6	45.5	63.3

Worthy has become a popular variety in Michigan. It has met with particular favor in the "Thumb" district of the State. For further information on Worthy see Cox (1) and Spragg (5, 6).

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REGISTRATION OF IMPROVED WHEAT VARIETIES, II[1]

J. ALLEN CLARK, J. H. PARKER, AND L. R. WALDRON[2]

In continuation of the plan of the American Society of Agronomy for registering new varieties on the basis of performance, this paper is the report of the 1926–27 Sub-committee on wheat. Two earlier reports presented the registration of 229 standard varieties (3)[3] and 23 improved varieties (4). Another paper by the senior author (2) contains an alphabetical list of the 252 registered wheat varieties, their registration number, class, origin, and estimated acreage.

Applications for the registration of additional varieties, received by the committee, have been carefully considered. For those which have been approved, registration numbers have been assigned and certificates of registration have been issued to the applicant. The varieties approved, together with their registration numbers, are as follows:

Varietal Name	Registration Number
Nittany	254
Denton	255
Mondak	256
Supreme	257
Albit	258

The performance which is the basis for registering these varieties is given below.

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[1] Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Department of Agriculture, and the American Society of Agornomy. Received for publication, October 15, 1927.

[2] Agronomist in Charge of Western Wheat Investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture; Professor of Crop Improvement, Kansas Agricultural College, Manhattan, Kans.; and Plant Breeder, North Dakota Agricultural Experiment Station, Fargo, N. Dak., respectively. Members of 1926–27 Sub-committee of the American Society of Agronomy for the Registration of Wheat Varieties.

[3] Reference by number is to "Literature Cited," p. 1040.

NITTANY—Reg. No. 254

Nittany (Pa. No. 44; C. I. No. 6962) was developed at the Pennsylvania Agricultural Experiment Station, State College, Pa., as a pure-line selection from Fulcaster, made in 1909, by C. F. Noll, who applied for its registration. The variety has been grown commercially in Pennsylvania since 1918, as Pa. 44. The variety differs from Fulcaster in being a few days later, is taller, and has a ranker growth. The superior characters of Nittany are higher yields and good bread-making qualities. It has been grown experimentally for 12 years at State College, Pa., in duplicate plats with checks. The comparative data of Nittany, Fulcaster, Fultz, and Leap, the principal varieties in Pennsylvania, are as follows:

Yield in Bushels Per Acre[a]

						Averages	
Variety	1921	1923	1924	1925	1926	1921 to 1926	1914 to 1926
Nittany (new)	32.9	19.7	24.8	37.4	25.1	28.0	32.4
Fulcaster (standard)	28.3	16.6	20.4	34.2	21.9	24.3	27.9
Fultz (standard)	26.5	15.9	22.4	37.2	20.2	24.4	27.2
Leap (standard)	27.0	15.2	20.5	36.4	24.2	24.7	——

[a] In 1922 some plats were destroyed because of building operations.

For further information see bulletin by the Pennsylvania Agricultural Experiment Station (1).

DENTON—Reg. No. 255

Denton (Tex. No. 9236; C. I. No. 8265) was developed by the Texas Agricultural Experiment Station at Substation No. 6, Denton, Texas, as a pure-line selection from Mediterranean. The selection was made in 1918 at which time A. H. Leidigh was agronomist and C. H. McDowell was superintendent of Substation No. 6. P. B. Dunkle has been superintendent since 1922 and applied for the registration of Denton wheat. The variety was distributed for commercial growing in Texas in 1926. Denton (Mediterranean No.66) is the best of more than 500 pure-line selections of Mediterranean tested since 1920. In addition to its high yields it is resistant to leaf rust and has stronger stems than Mediterranean. It has been grown in replicated nursery and plat experiments at Substation No. 6 for six years. The yields obtained during the four years, 1923 to 1926, are as follows:

Variety	Yield in Bushels Per Acre				
	1923	1924	1925	1926	Average
Denton (new)	27.1	41.3	14.6	24.6	26.9
Mediterranean (standard)	22.8	31.4	11.0	27.5	23.2

MONDAK—Reg. No. 256

Mondak (C. I. No. 7287) was developed from cooperative experiments between the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, and the North Dakota and Montana agricultural experiment stations. It is the result of selections jointly planned by J. A. Clark and R. W. Smith, and made from Kubanka, C. I. No. 1440, in 1915 by R. W. Smith at the Dickinson Substation, Dickinson, N. Dak.

Several of the best selections from the nursery at Dickinson were increased and sent to the Judith Basin Substation, Moccasin, Mont., for growing in plat experiments in 1922. Mondak (Kubanka Sel. No. 74) proved to be the best selection or durum variety at that station. It was the highest yielding selection in the nursery at Dickinson, but in the plat experiments at that station it was outyielded by Nodak (Kubanka Sel. No. 98) and by the parent variety because of their greater resistance to stem rust. Mondak differs from Kubanka in being earlier or having a longer fruiting period, taller, and having better quality of grain for the manufacture of macaroni. Mondak is more susceptible to stem rust than Nodak or Kubanka and for that reason Mondak has been recommended for growing in western North Dakota and Montana where stem rust does not usually occur.

Mondak was first distributed for commercial growing from the Dickinson Substation in 1924 and by the Montana Experiment Station in 1926. Application for its registration was made by R. W. Smith and J. A. Clark. It has been under experiment for 10 years at Dickinson, N. Dak., and five years at Moccasin, Mont. The nursery yields in comparison with the parent Kubanka at Dickinson from 1917 to 1922, and the plat yields at Dickinson and Mocasin from 1922 to 1926, are as follows:

Variety	Nursery Yields in Bushels Per Acre						
	1917	1918	1919	1920	1921	1922	Average
Dickinson, N. Dak.							
Mondak (new)	16.0	21.0	3.6	30.0	16.0	20.8	17.9
Kubanka (standard)	12.6	16.2	2.9	30.6	12.9	19.3	15.8

	Plat Yields in Bushels Per Acre					
Dickinson, N. Dak.	1922	1923	1924	1925	1926	Average
Mondak	31.6	22.6	20.3	13.7	5.3	18.7
Kubanka	31.4	22.9	20.0	14.5	5.7	18.9
Moccasin, Mont.						
Mondak	30.7	28.2	26.3	22.3	30.0	27.5
Kubanka	24.8	25.6	27.7	21.2	28.4	25.5

For further information see Smith, Waldron, and Clark (6).

SUPREME—Reg. No. 257

Supreme (Mont. No. 531; C. I. No. 8026) was developed as a selection from Red Bobs by Seager Wheeler at Rosthern, Sask., Canada. Seed was obtained by the Agronomy Department of the Montana Agricultural Experiment Station from Seager Wheeler in March, 1922. The variety has been grown commercially in Canada since 1922 and in Montana since about 1924. It has outyielded Marquis in Montana, is four to seven days earlier, has stronger stems, and is equal in milling and baking quality. Prof. Clyde McKee, Agronomist of the Montana Agricultural Experiment Station, applied for the registration of Supreme. It has been under experiment at the Bozeman, Moccasin, and Havre stations in Montana, and the results obtained are as follows:

Yield in Bushels Per Acre

Station and variety	1922	1923	1924	1925	1926	Average
Bozeman						
Supreme (new)	78.0[a]	62.3	38.9	62.3	36.1	55.5
Marquis (standard)	64.3	57.2	36.5	47.4	42.1	49.5
Moccasin						
Supreme	27.0[b]	49.3[b]	38.6[b]	24.7	29.7	33.9
Marquis	28.4[b]	36.6[b]	37.6[b]	22.4	30.0	31.0
Havre						
Supreme	—	—	13.9	18.9	4.2	12.3
Marquis	—	—	12.3	16.4	2.8	10.5

[a] In single 1.40 acre plat, others from triplicate 1/40 acre plats.

[b] In nursery rod-rows, others from four 1/50 acre replicated plats.

ALBIT—Reg. No. 258

Albit (Wash. No. 2517; C.I. No. 8275) was developed by the Washington Agricultural Experiment Station at Pullman, Wash. It is the result of a cross between Hybrid 128 (female) and White Odessa (male) made in 1920 by E. F. Gaines. A selection made in 1923 resulted in the Albit variety. It is a club wheat with awnless spikes, glabrous white glumes, and soft white kernels. It is superior to Hybrid 128 in yield and is bunt resistant. It was released for commercial distribution in the fall of 1926. E. F. Gaines, Cerealist of the Washington Station, applied for its registration. It has been under experiment at Pullman, Wash., since 1924, the results being as follows:

Experiment and Variety	Yield in Bushels Per Acre			
	1924	1925	1926	Average
Nursery				
Albit (new)	46.8	49.7	49.8	48.8
Hybrid 128 (standard)	37.8	53.0	43.5	44.8
Ridit (standard)	35.5	40.3	43.7	39.8
Plat				
Albit	—	47.4	46.5	47.0
Hybrid 128	—	45.3	38.3	41.8
Ridit	—	43.0	39.3	41.2
Smut test	Bunt Infection, %			
Albit	0	0	0	0
Hybrid 128	18.0	55.0	84.0	52.0

For further information see bulletin by Schafer, Gaines, and Barbee (5).

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NOTE

SOME OBSERVATIONS ON THE USE OF ANIMAL MANURE AND CROP RESIDUES

In the conduct of field experiments on soil fertility at the central farm of the Kentucky Experiment Station at Lexington, it has been found that crop residues depress the yield of corn in rotation in which corn immediately follows the application of residues and fail to increase other crops in the rotation, while animal manure used in rotation increases the yield of corn and of other crops in the rotation. It was found further that a comparatively small amount of nitrate of soda is as effective in increasing crop yields under certain conditions as heavy applications of animal manure. Following are some data bearing upon these points.

Beginning in 1911, a series of field experiments was instituted in which various liming and fertilizer treatments are being tested. The rotation is corn (rye cover crop), soybeans, wheat, and clover and occupies four series of plats. The land was broken in 1899 out of bluegrass of several years' standing and was used for general cropping until 1911 without any return of manure, so far as any records show.

During the first round of the rotation no provision was made for the return of organic matter, all crops being removed except the second crop of clover. Beginning with the second round of the rotation, the corn stalks were left on the ground and the soybean straw and wheat straw were returned to the clover sod to be broken for corn, with the exception of plats 5 and 10.[1] The second crop of clover was left on all plats. Plat 5 was treated with acid phosphate and potash and will be compared with plat 4 similarly treated with acid phosphate and potash and receiving crop residues. Plat 10 has had no fertilizer or crop residue treatment and will be compared with plat 13 receiving crop residues as indicated above. The average annual return of soybean straw was approximately 2,400 pounds per acre and of wheat straw approximately 2,600 pounds per acre.

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[1] The details of these experiments will be found in Bulletin No. 272 of the Kentucky Experiment Station.

The straw has generally, though not always, been spread in the fall and the plowing has nearly always been done in the spring.

Following are the average corn yields per acre by rotations on these four sets of plats:

	Plat 5, PK	Plat 4, PKR	Difference	Plat 10, no treatment	Plat 13, R	Difference
1st rotation	38.0	34.9	+3.1	47.2	49.2	—2.0
2d rotation[a]	57.0 (51.7)	55.2 (48.4)	+1.8 (+3.3)	63.2 (57.8)	63.6 (58.2)	—0.4
3d rotation	41.7	37.1	+4.6	46.8	42.7	+4.1
4th rotation	65.7	59.2	+6.5	67.4	62.1	+5.3
Average 2d, 3d, and 4th rotations	54.8	50.5	+4.3 (+4.8)	59.1	56.1	+3.0

[a] Only three of the four crops of the second rotation were affected by residues. Average of these crops in parenthesis.

It will be observed that in both pairs of plats the yield of corn changed gradually through the period in favor of the plats not receiving residues.

In the case of the other crops in the rotation the yields have been almost the same in the two members in each pair of plats, both before and after the use of residues. The yield of beans has been about 18 bushels, wheat 25 bushels, and clover hay a little over 2 tons.

In each series of plats were duplicates (9 and 15) treated with lime, acid phosphate, and potash and receiving residues as indicated above. Beginning in 1924 manure was used on plat 15 instead of crop residues and was applied on the corn ground in weights equal to the crops removed from plat 15 in the four series the preceding year. Crop residues were continued on plat 9. From 1911 to 1923 the average yields of corn for plats 9 and 15 were 53.4 bushels and 46.2 bushels, respectively. For 1924 to 1926 the average yields were 63.1 bushels and 66.9 bushels, respectively. Plats 9 and 15 on series 100 are left out of these averages since manure was used on plat 15 only on series 200, 300, and 400.

In 1920 a manuring experiment was begun in a rotation of corn, wheat, and clover on soil of about the same character and fertility as in the four-year rotation above. The average yield of corn for 1920 to 1926 was 63.2 bushels per acre on plat 7 receiving 4 tons of manure per acre applied to the broken ground and disked in, while the average yield for the two check plats (5 and 9) between which plat 7 lies was 55.9 bushels per acre. The average yield for the same seven years in the four-year rotation just discussed was 56.4 bushels per acre on the plats receiving no treatment and 52.1 bushels on the plats receiving residues. Wheat in this rotation has been materially increased by the use of manure for the corn, the increases being 2.3, 3.3, 4.3, and 5.4 for 4,6,8, and 10 tons of manure, respectively. The yields of clover and soybeans (soybeans used two years when clover failed) were increased by the use of manure for corn, the increase ranging from 190 to 433 pounds per acre.

In a three-year rotation of corn, wheat, and clover contiguous to the four-year rotation and started at the same time, a plat (16) to which wheat straw and cornstalks have been returned has produced an average yield of 55.5 bushels per acre during the period 1920 to 1926, which is almost exactly the same as the yields on the untreated plats of the four-year rotation and of the three-year rotation in which manuring experiments are conducted.

In almost every season moisture is a limiting factor for corn on these soils. The yields have varied from 80 bushels in the better seasons to as low as 10 bushels in dry seasons. The amount of organic matter added in residues has evidently not affected the moisture relations favorably; at least not enough to overcome the bad effects of residues, whatever they may be. In the manuring experiments referred to above, 10 tons of manure per acre did not produce an appreciably greater yield of corn than 4 tons and has not, therefore, materially affected the moisture relations with respect to the corn crop.

Evidence from other experiments on the Station farm indicates that organic matter added beyond the accumulation from root and stubble in a good rotation has no value beyond the plant food added.

In a six-year rotation consisting of 2 years of tobacco, wheat, clover, and bluegrass two years, all crops were removed including the bluegrass. As an average of seven years, 200 pounds of nitrate of soda per acre on each of the tobacco crops has increased the yield 209 pounds per acre, while 10 tons of manure on the first of the two tobacco crops has increased the yield 93 pounds per acre. The residual effect of the manure on the second crop was more than two and one-half times greater than its effect on the first crop. Heavy additions of potash and phosphate with the nitrate of soda have not increased the average yield. In these cases every other plat was used as a check, and three series of plats were used to accommodate the rotation.

In a four-year rotation of tobacco, wheat, clover, and orchard grass the yield of tobacco without fertilizer or manure treatment has been 1,312 pounds per acre as an average of 11 years. With 200 pounds of nitrate of soda per acre in the same rotation the yield has been increased 198 pounds. With 20 tons of manure per acre per year (except 1926 when it was reduced to 10 tons), the yield has been increased 227 pounds per acre. This work was done in duplicate.

These results seem to conform to Thorne's thesis[2] that organic matter added beyond the accumulation from root and stubble in a good rotation is valuable chiefly, and perhaps only, for the plant food constituents it adds. The failure of crop residues to increase yields may be due to the use of soil nitrates by organisms effecting the decomposition of organic matter. Not enough nitrate determinations have yet been made on these plats to warrant a statement that this is the cause.

These soils are unusually well supplied with minerals. The soil of the four-year rotation contains, in 2,000,000 pounds of soil, approximately 10,000 pounds of phosphorus, 25,000 pounds of potassium, 14,000 pounds easily soluble calcium, and 4,500 pounds of nitrogen. These figures are from analyses made of the soil at the beginning of the work.

Judging from the yields of the untreated plats, there must be considerable nitrogen fixation taking place but not enough to remove the nitrogen limit, if one may judge by the yields of corn in the manuring experiments and from the yields of tobacco where fertilizers and manure have been used.—GEORGE ROBERTS, *Agronomist, Kentucky Agricultural Experiment Station, Lexington, Ky.*

[2] THORNE, C. E. The function of organic matter in the soil. Jour. Amer. Soc. Agron., 18:767–793. 1926.

AGRONOMIC AFFAIRS

MINUTES OF THE AGRONOMY SECTION, SOUTHERN AGRICULTURAL WORKERS' ASSOCIATION, ATLANTA, GEORGIA, 1927

WEDNESDAY, FEBRUARY 2, 2:00 P. M.

The Section met in the Grill-room of the Biltmore Hotel with R. P. Bledsoe, Chairman, R. W. Hamilton, Vice-chairman, and P. H. Kime, Secretary.

The following program was presented:

1. Crotalaria as a Soil-Building Crop for Florida, W. E. Stokes, Florida Experiment Station, Gainesville, Florida.

(Appears in October number of this JOURNAL)

2. Preliminary Studies on Time of Turning Vetch and its Relative Value as a Source of Nitrogen for Cotton and Corn, M. J. Funchess, Alabama Experiment Station, Auburn, Ala.

A short discussion of similar work carried on at the Georgia Experiment Station was presented by R. P. Bledsoe.

3. Concentrated Fertilizer Experiments, J. J. Skinner, Bureau of Plant Industry, Washington, D. C.

(Abstract in August number of this JOURNAL)

4. The Concentration of Phosphorus in the Soil Solution and Its Relation to Plant Growth, F. W. Parker, Alabama Experiment Station, Auburn, Ala.

5. Some Factors which will Materially affect the Profitableness of the Production of Cotton in the South in 1927, C. B. Williams, North Carolina Experiment Station, Raleigh, N. C.

REPORT OF COMMITTEES

The committee on soils and fertilizers did not submit a report.

The report of the crops committee was read by J. F. O'Kelley and adopted by the section.

The following committees were appointed:

Nominating Committee: R. Y. Winters, Chairman, North Carolina; F. W. Parker, Alabama; and J. F. O'Kelley, Mississippi.

A committee was also appointed to meet with a delegation from the Dairy Section to consider holding a joint session of the two groups at the 1928 meeting. This Committee was as follows: M. J. Funches, Alabama, Chairman; C. E. Chambliss, Bureau of Plant Industry, U. S. Department of Agriculture; and Paul Tabor, Georgia.

THURSDAY, FEBRUARY 3, 2:00 P. M.

The meeting was called to order by Chairman Bledsoe and the following program presented:

1. Cotton Research at the Southern Agricultural Experiment Stations, H. M. Steece, Office of Experiment Stations, Washington, D. C.

2. Farm Management and Organization in Cotton Production, H. R. Tolley, Bureau of Agricultural Economics, Washington, D. C.

This subject was also discussed by G. W. Forster, North Carolina State College, and J. R. Fain of the Georgia State College of Agriculture. Mr. Fain's paper was read by Mr. E. C. Westbrook of Georgia.

3. Spinning Qualities of Some Cottons Grown in the South Atlantic States, H. H. Willis, Bureau of Agricultural Economics, Washington, D. C.

(Resume appears in October number of this JOURNAL)

4. The relation of Staple to Yield and Value per acre of Cotton in the Southeastern States, R. R. Childs, Georgia State College.

(Abstract in August number of this JOURNAL)

A few comments were made by W. E. Ayers of the Delta Station, Stoneville, Mississippi, and H. B. Brown of the Louisiana Experiment Station, Baton Rouge, La.

REPORT OF COMMITTEES

The committee appointed to meet with the dairy committee recommended that a preliminary meeting of the agronomists and dairy specialists be held during the summer and that they work out plans for a joint program for the 1928 meeting. The recommendations were endorsed by the Section.

The report of the committee on nominations was presented and the nominations approved as follows: T. B. Hutcheson, Virginia, Chairman; E.C.Westbrook, Georgia, Vice-chairman; W. E. Ayers, Mississippi, Secretary; C. E. Chambliss, Representative of the U. S. Department of Agriculture, Washington, D. C.; and M. J. Funchess, Alabama, Representative of the American Society of Agronomy.

The committees on crops and on soils and fertilizers were not appointed. The nominating committee recommended that the men doing cooperative work in these two fields make the report and appoint one of their group to present it.

Dr. Winters read a letter from Dr. P. E. Brown, Secretary of the American Society of Agronomy, inviting the Agronomy Section of the Southern Agricultural Workers' Association to meet with the American Society of Agronomy Section of the American Association for the Advancement of Science in Nashville during the latter part of December, 1927. The Section declined the invitation on the ground that many of the agronomists would not have travel funds to attend this meeting and also the Southern Agricultural Workers' Association a month later. It was the general opinion of the Section that the members should attend the regular meeting of the Southern Agricultural Workers' Association and that any one who desired might attend the Nashville meeting also.—R. P. BLEDSOE, *Chairman*, and P. H. KIME, *Secretary*.

MEETING OF THE SOUTHERN SECTION OF THE SOCIETY

The Southern Section of the American Society of Agronomy held its first summer meeting at the Alabama Station, August 24 and 25, 1927. The meeting was attended by 50 agronomists and others interested in Agronomy, representing eight southern states.

The following program was presented by the Agronomy Department of the Alabama Station.

AUGUST 24

8:00 A. M.

The Purpose of the Summer Meeting, by M. J. Funchess.

Inspection of the Experiment Station farm. Special attention was given to the following plats:

1. Rotation experiments
    - a. Old rotation, now in 32nd year.
    - b. Cullars rotation, now in 17th year.

2. Time of turning vetch for cotton and corn. This includes a comparison of vetch with different amounts of nitrate of soda.
3. Comparison of vetch, manure, and nitrate for cotton and corn.
4. Comparison of different nitrogenous fertilizers.
    a. Old series started in 1911.
    b. Ammonium sulfate and sodium nitrate on limed and unlimed land. In third crop.
    c. Plats of cooperative Purnell project.
5. Rate of fertilizing cotton with and without poisoning for boll weevil.
6. Concentrated vs. ordinary fertilizers.
7. Variety tests of cotton and soybeans.
8. Methods of preparation of land for cotton.
9. Cotton spacing experiments.

1:30 P. M.

Results of Rotation Experiments, by M. J. Funchess.

(To be published.)

Cooperative Cotton Fertilizer Experiments, by J. T. Williamson.

(To be published.)

Cotton Spacing, by H. B. Tisdale.

(To be published.)

The Influence of Time of Planting and of Cutting on the Yield and Nitrogen Content of Vetch and Austrian Peas, by M. J. Funchess.

(To be published.)

Winter Legumes for Corn and Cotton, by M. J. Funchess.

(To be published.)

7:30 P. M.

Informal meeting at Comer Hall

Inspection of laboratories and greenhouses of the Agronomy Department.

AUGUST 25

8:00 A. M.

The Purpose and Methods of a Soil Research Laboratory, by F. W. Parker.

The Buffer Capacity of Soils and the Influence of Different Nitrogenous Fertilizers on the Soil Reaction, by W. H. Pierre.

(To be published.)

The Influence of Different Nitrogenous Fertilzers on the Availability of Phosphorus. A preliminary report, by J. F. Fudge.

(To be published.)

Business meeting.

1:00–7:00 P. M.

Tour of several counties in Alabama, including part of the Black Belt.

At the close of the meeting the section voted to meet each summer with the next meeting at the Mississippi Station during the latter part of August, 1928.—M. J. FUNCHESS, *Director, Alabama Experiment Station, Auburn, Ala.*

NEWS ITEMS

T. K. WOLFE, Professor of Agronomy, Virginia Polytechnic Institute, and Agronomist, Virginia Agricultural Experiment Station, has resigned to become Editor of The Southern Planter, Richmond, Virginia. He assumed his new duties September 1, 1927.

S. B. HASKELL has resigned as Director of the Massachusetts Agricultural Experiment Station, effective December 15, to become manager for the United States, Hawaii, Cuba, and Porto Rico of the Agricultural Department of the Synthetic Products Corporation with headquarters at New York City.

AT A RECENT celebration of its semi-centennial the University of Toronto conferred the honorary degree of doctor of science upon Frederick J. Alway, head of the Division of Soil Chemistry at the University of Minnesota.

ERRATUM

On page 892 of the October number of the JOURNAL in the sentence beginning, "In the first analysis, * * *, plats numbered 1 to 1 and 16 to 1, etc.", should read plats 1-1, 16-1, etc., indicating plat 1 of row 1, plat 1 of row 16, etc.

JOURNAL
OF THE
American Society of Agronomy

VOL. 19 DECEMBER, 1927 No. 12

MEETING OUR RESPONSIBILITIES IN AGRONOMIC RESEARCH[1]

W. L. BURLISON[2]

The agronomist should be and is proud of his job. His work is basic to the public welfare because our food supply is dependent to a very large extent on the field to which the agronomist is devoting his life work. Agronomy has to do with a business representing in this country, in material wealth alone, an amount reaching toward 10 billion dollars annually. Last year the income from America's field crops reached the substantial sum of $9,001,682,000.

In so important a business it is well for us to stop along the way occasionally to take inventory; to see where we are, so to speak. In commercial business it is customary to find the outgo as well as the income of the business; possibly agronomists might receive helpful suggestions through some such procedure.

Agriculturally, times are hard, and it is doubtful if the agronomist has ever had greater need for a careful review of his whole program than now.

The amount of agronomic work under way in the United States is extensive, and yet we are just nibbling at the edge of things Of the 6,710 active projects being prosecuted by American experiment stations, 2,156 are agronomic in character, being classified under the headings of farm crops, soils, and fertilizers. Thus the agronomists are responsible for something like one-third of the research in our agricultural experiment stations. Does not this fact furnish a real challenge to all men engaged in agronomy?

During the year 1926 the experiment stations of the United States expended about 12 million dollars, more than 2 million of which was received from federal funds. A very large share of the sum was spent in agronomic research. We would not be far wrong to assume that agronomy spent three to four millions of this sum. Facts like these bring home the tremendous responsibility placed upon us as agronomists in the proper expenditure of the people's money. They suggest the importance of examining each project perhaps even more thoroughly than has been our custom. There is not much doubt in my mind that we shall be called upon, sooner or later, to render an account of our stewardship, and this means that we must very carefully take stock of our research affairs.

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[1] Presidential address read at the annual meeting of the American Society of Agronomy, at Chicago, Ill., November 17, 1927.

[2] Chief in Crop Production and Head of Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of Dean H. W. Mumford, College of Agriculture, University of Illinois.

For some time it has been my pleasure to study the personnel of our agronomy departments throughout the country and it is a real satisfaction to pay tribute here to the excellent character and quality of these men. Figures for the year 1926 show a list of approximately 600 men in the various colleges of agriculture and experiment stations, aside from the large group in the United States Department of Agriculture, who are faithfully devoting their time to agronomic research.

The academic training of our people is of special interest to us. About 120 of this group of state experiment station workers have attained the doctor's degree, 241 have proceeded to the master's degree, and 208 have no record beyond the baccalaureate degree. Doubtless the agronomic staff of this country will compare favorably with any group of station workers as to academic preparation. However, an examination of the number of graduate students in this field is not so encouraging as it might be. We would do well to encourage more high grade men to continue their graduate studies, for as sure as we are gathered here there is going to be a scarcity of adequately trained men for agronomic teaching and research. Even at this time it is extremely difficult to find a sufficient number of first class young men well trained in the fundamental sciences underlying agronomic research. In my opinion, this is a condition which should be taken seriously by all of us. Now, while agriculture is not so prosperous, is an opportune time for the young agronomist to prepare for the future need, for it seems to me that we are entering upon a period of agronomic research which will require a large number of workers thoroughly trained and of wide experience. A new epoch in agronomic research is upon us; the old day is passing.

A LOOK BACKWARD[3]

A look back over the world's literature reveals the fact that,

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[3] Literature review based on Edward J. Russell's, "Soil Conditions and Plant Growth." Ed. 4.

"throughout all ages the growth of plants has interested thoughtful men. . . ."; that "the mystery of the change of an apparently lifeless seed to a vigorous growing plant never loses its freshness." As time goes on and the world's food problem becomes more complex and more serious, this interest should steadily increase.

A review of some of the world's literature relating to agriculture reveals many interesting statements defining stages through which plant science has passed. At one time it was thought by some gardeners that the moon exercised a controlling influence on the growth of plants. Others believed that the ruling force was an unknown God whose power could never be known. Before the fifteenth century, speculation and superstition ruled supreme. Since about the middle of the fifteenth century, plant culture studies have passed through certain rather well-defined epochs, each in turn contributing valuable information to our knowledge of how plants grow.

Almost five centuries ago, Palissy said, "You will admit that when you bring dung into the field it is to return to the soil something that has been taken away. Have you not seen certain labourers when sowing a field with wheat for the second year in succession, burn the unused wheat straw which had been taken from the field? In the ashes will be found the salt that the straw took out of the soil; if this is put back, the soil is improved." These facts have been confirmed in part from the study of chemistry.

Early in the sixteenth century, a search for the "principle of vegetation" was begun by Von Helmont. His work is regarded as the classic of its time, and opened important new fields of plant studies.

About the middle of the sixteenth century, Tull wrote interestingly of how plants feed. "It is agreed," he wrote,"that all the following materials contribute in some manner to the increase of plants, but it is disputed which of them is that very increase of food: (1) Niter, (2) Water, (3) Air, (4) Fire, (5) Earth. . . . Although niter, water, air, and fire and heat aid plants in growing, the earth is the real food and increase of plants." Tull's work closes the period known as the epoch of a search for the "principle of vegetation."

The year 1750 seems to mark the beginning of the epoch regarded as a search for "plant nutrients." It was about 1755 when Home was set to work by the Edinburg Society "to try how far chemistry will go in settling the principles of agriculture." His chief contribution to plant culture was the emphasis he placed on a study of the function of plant nutrients.

Priestley, in 1771, pointed to the fact "that plants instead of affecting the air in the same manner as animal respiration, reverse the effects of breathing and tend to keep the atmosphere pure and wholesome." Upon the observations just cited, coupled with Priestley's discovery of oxygen, is based one of the most important principles of plant physiology.

Up to about 1800, studies were largely of a qualitative nature, but the work of DeSaussure on quantitative gaseous exchange in plants laid the foundation for work now included in the modern period of plant investigations. DeSaussure, however, viewed his studies largely from the chemical aspect, being less interested in their direct application to the science of plant life.

Early in the nineteenth century, Liebig referred to the work up to his time as being of a nature "fitted only to awake pity." Liebig announced that, "the crops on a field diminish or increase in exact proportion to the diminution or increase of the substances conveyed to it in manure." The fundamental truths that he contributed marked the beginning of a new era and he prepared the world for the splendid progress that followed.

In April 1859, Sachs was called by Professor Stöckhardt to the experiment station at Tharand to perfect and extend his researches on the nutrient solution and to direct the work of the experiment station along lines of experimental plant physiology. Later, at the Agricultural Academy at Bonn-Poppelsdorf, he gave us the now classic contribution on germination, material transportation, and translocation, and thus laid broad and deep the foundations for an experimental study of plant nutrition. His chief interest in botany seemed to be in its application to agriculture. The intimate and definite relation between the two fields so well recognized by Stöckhardt and masterfully developed by Sachs was all but broken with the latter's passing. A field so auspiciously developed has been allowed to lie practically fallow for more than half a century.

A LOOK FORWARD

Just why botanists of the immediate past have overlooked such an opportunity for service is not clear. If the botanists are somewhat at fault, so are the agronomists. Good botanical training has been available to them, but few have sought such equipment as botany can give. It must be admitted that both groups are at fault, and as a result, fundamental investigations in crops have been few in number and the progress on these has been slow. We have scarcely emerged from the variety testing stage—the "cut and try" epoch.

The contributions of chemistry to modern civilization have been so numerous and important that the present era has been referred to as the chemical age. The applications furnished agriculture are fundamentally important and are recognized as such, but we believe chemistry cannot solve our crop production problems unaided. It appears now that a newer plant physiology, quantitative in nature, is destined to enter the field of action along with chemistry, and from this combination much is to be expected.

In the corn belt live two corn breeders of national reputation—if not international reputation. Not many years ago, the older of them was heard to say, "I have studied corn breeding for thirty years and I am only in the A-B-C class." The other has remarked that "after nine years of patient endeavor, I have little to say because my results seem to be so difficult of interpretation." These statements confirm us in the belief that our botanical truths are not sufficient in themselves to furnish a foundation on which to build breeding operations.

If agronomy is to occupy the important station it should, it must ally itself with those sciences that are basic in the interpretation of plant function, namely, chemistry, physics, and plant physiology. By establishing the closest relationship workers in these fields can contribute largely to the solution of the intricate and basic problems that confront us concerning the influence of the agricultural environment on plant functions.

THE CROP PRODUCTION PROBLEM

So far as crop production is concerned, what are some of its basic problems? What contributions to the solution of these problems can plant physiology make?

As an aid to clarifying these problems it will be well to consider briefly some of the general geographic features of a single state. For example, let us take Illinois which from north to south, is 385 miles long. This means, of course, great variation in the climate of the respective sections. Northern Illinois receives an annual rainfall of less than 35 inches, while the southern third of the state receives from 40 to 50 inches. Temperature variations for these areas are even more striking than rainfall differences, thus causing marked variation in the length of the crop-growing seasons. At Fairfield corn may be planted during the last days of April, while at DeKalb, May 18 is the earliest date.

The soil survey of Illinois shows great variations in types. To date, many distinguishable types have been recorded varying from drifting sands to heavy clays. Such extremes indicate clearly the complex nature of the crop production problem with which we have to deal. With such great variation in soils and climate as we have in Illinois, might not a farmer successful in southern Illinois prove a failure in the northern portion of the state?

A satisfactory solution of crop-production problems must be founded on a full knowledge of the soil and of what is taking place in it, and at the same time on a complete understanding of the influence of climate and the inter-relationship of all the involved factors affecting plant growth. Much has been done toward the solution of the soil problems, though many vital questions remain unanswered. It will be some time before plant studies have reached the same stage of progress as soil studies. Hence, in order that soils work may proceed, plant research basic in character must be prosecuted most vigorously.

What are the outstanding crop problems which should be attacked first? It seems to me that one of these is the whole question of "adaptation." If this is granted, what then shall be the method of attack? We believe the approach must be made through a study of plant physiology. "The aim of plant physiology," as stated by the great botanist Palladin, "is to gain a complete and thorough knowledge of all the phenomena occurring in plants, to analyze the complex life processes so as to interpret them in terms of simple ones and to reduce them finally to principles of physics and chemistry."

Little is now known of the sensitive or critical periods in crop plants in relation to such factors as moisture, temperature, and light, as viewed from the physiological aspect, more particularly in its application to field conditions. The basis of attack then, must be the study of the relationship of environmental factors to the various life stages of crop plants. These life stages or physiologic phases may, for the present at least, be grouped as follows: (1) The seed stage; (2) the germinative stage; (3) the plantlet stage; (4) the active growth or vegetative stage; and (5) the reproductive stage.

A thorough knowledge of the physiological behavior of farm crops must include a knowledge of the life stages, each in relation to the manifold combination in which the several factors of environment may appear. We are convinced that a clear understanding of the critical phase is necessary before we can proceed far in crop-adaptation studies.

A few typical questions will add emphasis to the suggestion made above.

1. One variety of wheat, corn, or oats is better than another. Why?

2. If this variety lodges worse than another, why?

3. If early seeding of spring wheat is best, why?
4. This year we have scab, next year none. Why?
5. Wheat winterkills. Why?
6. Soft wheat for southern locality, hard wheat for another section. Why?
7. Bearded wheat here and smooth wheat there. Why?
8. Today "I plant corn, tomorrow I plant from the same bag, and from today's planting I get a stand, from tomorrow's planting, a poor stand of puny corn." Why?

Truly a new day is dawning in agriculture when we begin to ply that question "WHY." The man on the land is once again facing the east, with always in the forefront the eternal question, WHY? It seems clear that the agronomist has come finally to realize his position and he now resolutely acknowledges the basic question—WHY?

WHAT IS BEING DONE TOWARD SOLVING THESE PROBLEMS?

If there is a new day in plant culture, the question arises in our minds, what are we doing to solve these important questions? Is everything being done that can be done? It is doubtful. There are famous plant physiologists and pathologists doing splendid work in their fields, many of whom through their laboratories would be happy to give of their best in solving these problems. This arrangement is being carried out in a few instances with marked success. In these laboratories without doubt, basic problems are under way. Great, indeed, is the hope for progress when the plant physiologist in his laboratory and the agronomist in his field are found working hand in hand looking for the "WHY" of these vital problems.

It seems difficult to explain why so little investigational work has been done on a crop like corn of which Illinois alone produces 355,000,000 bushels annually and of which the value in the United States is many millions of dollars. It is doubtful if we can find data which show the best temperature for the germination test of corn. What is the optimum temperature for germination? Should the temperature be 75° or 85°? What influence do the temperature relationships have on the development of the corn plant in its several life stages? Through the whole literature on corn, you may search for this kind of information, with little success.

Just as the physician understands the human body, so must the agronomist understand the plant body. If we are to understand the abnormal, or the plant in sickness, we must know the healthy or normal, because it is on the normal behavior that our recommendations for management are based.

Much has been written about the selection and storage of seed corn, but we are unable to find in literature sufficient data on this important subject to satisfy farmers of the corn belt. At what temperature should seed corn be stored for the maintenance of maximum germination and vigor? When seed corn is brought in from the field, how rapidly should it be dried and at what temperature? What temperature and moisture content should be maintained throughout the winter months? A line of work now under way shows clearly that there is danger of reducing too much the moisture content of seed corn. Corn dried to 6% moisture previous to storage was slower in absorbing water and more tardy in germination than similar corn stored with 12% moisture. The total percentage germination was lower and the vigor of the young plants was slightly less in the low-moisture corn. On the other hand, another lot of the same corn which contained 19% water when it was stored did not do so well as the dry corn, even though the processes of germination were more rapid. This suggests that the proper quantity of moisture for retaining vigor of seed corn in storage is nearer 12% than either 6 or 19. In other words, the quantity of water that permits the proper amount of physiological activity in the seed and insures the nourishment of the young plantlet and keeps it at its best is about 12%.

What is the best moisture content for corn at planting? Some time ago, one of the nation's leading farmers raised this question and emphasized its importance. No doubt the experience has taught him that the plants which are earliest and best established have the advantage over those less ready in their response. Preliminary studies indicate that soaking seed corn in water previous to planting hastens germination, thereby giving the plant an earlier start than otherwise would be the case. This preliminary soaking has resulted in an increase in the yield where the crop was planted late. However, the length of time the kernels are soaked determines whether the result will be an increase or a decrease in production. Soaking for periods less than 24 hours is favorable to growth, whereas, soaking for a longer time either is not beneficial or is detrimental. There are some indications that the benefit to be derived from this practice of soaking is dependent upon the time of planting and the moisture content of the soil when the planting is done. These are typical of the problems now being studied dealing with the seed stage of the corn plant.

It has been pointed out that corn for seed may be gathered in the milk stage. Seed thus selected will germinate, but it is an easy prey for fungi, and in many instances the plants grown from it might never appear above ground. It has been clearly demonstrated that thoroughly mature corn is best for seed, because fully developed seed possesses a greater degree of resistance. Disease organisms may be present but they are unable to get a hold on the vigorous, healthy grain, while the early selected seed may fall an easy prey to molds by the end of the third day of the germination test.

In field practice, what should be the temperature and moisture content of the soil to give the little corn plant a rapid start? The problems with the plantlet are of the same sort as those having to do with the germination stage. An important study has been concluded and the material published on the relation of early vigor of the corn plant to yield. This problem concerns itself with the plantlet stage primarily.

The Illinois Experiment Station has data covering 12 years' work on the frequency of the cultivation of corn. It is impossible to interpret these figures because so little is known regarding the nutrition cycle of corn. If cultivation assists in nitrate production, is the cultivation performed at such a time and under such conditions as will render these nitrates available at the stage or phase that the growing plant needs therein? The growing plant undegoes rapid changes in its nutrient requirements and reacts in its several growth phases in a widely varying manner. The nutrient element required today may not be liberated until tomorrow; and the factors which underlie increased growth and reproduction one day may, on another day and in a different growth phase, lead to decreased production.

Researches conducted at the University of Wisconsin point to a relatively high optimum temperature for the growth and sporulation of wheat scab and corn rot organism, *Gibberella saubinetii*. When this fungus infects corn and wheat seedlings, the maximum development occurs at widely different temperatures. On wheat growing under greenhouse conditions, the fungus behaves normally as we would expect it to. Its growth is the most rapid and the greatest injury is caused to the host when the temperature is high. When grown on corn, practically the reverse is true. The greatest growth of fungus and the least growth of the young corn plant takes place under relatively low temperature environment. This would suggest the disirability of planting corn late in the season when the temperature is high. However, certain experiments with diseased corn show that when planting is delayed the severity of the disease is increased, the yield reduced, and the quality of grain lowered. Thus, it appears that two organisms that have similar optimum temperature requirements when grown alone, may have widely different requirements for their best growth when one is allowed to parasitize the other. Also, when any one of the controlled standard conditions is changed, the relationship of the host and parasite is affected. In other words, there seems to exist in nature a state of equilibrium between plants and the various factors which make up their environment. When one or more of these factors are altered, the effect of the others is changed and the equilibrium disturbed.

Further, our corn-rot investigations bring sharply to mind the problem of disease resistance and immunity. One instance will suffice to bring this point clearly before us. We have two lots of corn, one lot very much like the other, and when planted on clean land the yields are about the same, but when planted on infested land the yield of one is reduced about 52% and that of the other only about 2%. Why this great difference? We naturally ask ourselves, what is disease resistance and what is immunity to disease?

Such problems are typical of studies in the physiological behavior of different strains or varieties of corn, and upon such studies must be based sound field practices. Answers to such questions will give us the key to the crop-adaptation puzzle.

Wheat is our most important small grain, therefore, it is fitting that some time be given to the underlying principles of its management. Turkey Red is the most widely grown winter wheat. It is a leading wheat for central Illinois, and our winters are rarely ever severe enough to injure this variety. Red Rock, a wheat well adapted in Michigan, often completely winter-kills in Illinois. Why this difference in adaptation to climate? At the present time an effort is being made to determine the best moisture and temperature at time of germination, since reaction to moisture and temperature are factors which are believed to be of large significance in determining how varieties differ.

The Illinois Station has completed five years' work on the time of seeding spring wheat. The yield from the early March seeding is about 27 bushels; that from the April seeding is 22 bushels per acre. Is this difference obtained because these spring wheats develop greater vigor by being seeded early, when temperature is low? Or is it that the crop seeded early develops its flowers early, thereby avoiding the harmful influence of the hot weather of late June or early July? Marquis spring wheat is a highly satisfactory wheat for DeKalb, 125 miles north of Urbana, while Illinois No. 1 leads Marquis at Urbana by 6 bushels per acre. It has been found that Marquis germinates at a lower temperature than Illinois No. 1. One fundamental difference, therefore, between these varieties is in the temperature most desirable for germination, a fact which suggests why Marquis is better for northern Illinois and Illinois No. 1 is more satisfactory for central Illinois.

All these studies aim at an understanding of the normal life cycle of the crops studied; an understanding of which is necessary before an accurate determination of the adaptability of any crop can be made.

These are all simple illustrations of the problems involved in crop improvement. Hundreds of others could be cited, but the above are sufficient to illustrate the complex but important problems which men of good training and deep insight will be called on to solve.

To summarize briefly these remarks, it seems to me that we can more nearly meet our responsibilities in agronomic research:

1. By reviewing most carefully our research projects with a view to determining their fitness to present day needs.
2. By doing all we can to stimulate further graduate study on the part of those who are to carry out agronomic research in the future.
3. By seeking to find basic problems and then to carry to completion the investigation of these problems in a thoroughly scientific manner.

Finally, in the words of Daniel Webster, "Let us develop the resources of our land, call forth its powers, promote all its great interests, to see whether we also, in our day and generation, may not perform something to be remembered."

INHERITANCE OF EARLINESS IN CERTAIN VARIETIES OF SPRING WHEAT[1]

F. E. STEPHENS[2]

EARLINESS IN WHEAT

Earliness, or date of maturity, in wheat seems to coincide with other quantitative characters in mode of inheritance. Most of the genetic studies with wheat have dealt with qualitative characters rather than with quantitative or physiological differences, although many of the latter are equally important. The present paper is concerned with a study of a quantitative character, the inheritance of earliness in certain varieties of spring wheat. An effort has been made to determine the nature of inheritance of earliness in the varieties used and to observe any correlation that might exist between earliness and other characters

REVIEW OF LITERATURE

Studies of the inheritance of time of flowering or date of maturity have been made with a number of plants. In Mendel's (12)[3] original paper he states that the time of flowering in peas is intermediate between that of the parents and suggests that the "constitution of the hybrids with respect to this character probably follows the rule ascertained in the case of the other characters." He further emphasizes the importance of considering environmental conditions in studying this character.

Keeble and Pellew (10), also working with peas, considered lateness in time of flowering to be dominant over earliness. They also found a relation between certain morphological characters and the period of flowering. Late-flowering plants had a higher percentage of thick-stemmed individuals, while thin-stemmed individuals were predominant in the earlier plants.

Hoshino's (9) work with peas showed that the date of flowering in F_1 was nearer that of the late parent. The range of variation of the F_2 progeny extended from the date of flowering of the early parent to that of the late parent, with the minimum frequencies lying between the two. He explained these results by assuming the presence of two allelomorphic pairs of factors each of which has a specific hereditary effect. Variations which could not be attributed to the action of these factors he assigned to a "contamination" of genes.

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[1] Paper 154, Department of Plant Breeding, Cornell University, Ithaca, New York. Also presented to the Faculty of the Graduate School of Cornell University as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy. Received for publication Sept. 6, 1927.

[2] State Agricultural Inspector, Salt Lake City, Utah.

[3] Reference by number is to "Literature Cited," p. 1090.

In rice, he found the time of emergence of the heads in the F_1 to be nearer that of the early parent. In F_2 the range of variation extended from the dates of emergence of the early to those of the late parents, with the minimum frequency lying between the two and the earlier group being the larger. He explained these results on a three-factor hypothesis.

Leake (11), working with blossoming time of cotton, found the F_1 plants to be intermediate in time of flowering, with the mean of the F_2's nearer the late parent.

Emerson and East (6) considered the time of appearance of the silk as an indication of earliness in corn. In general, ripening occurred in the same order. They found the F_1 material intermediate between the parents with the F_2 progenies practically covering the range between the parents. They were able to isolate types as early as the early variety, but none quite so late as the late variety.

Caporn (3), writing on earliness in oats, draws his conclusions largely from F_3 results. He considers that there is ground for assuming that early and late ripening are Mendelian characters, but that they are dependent upon more than one factor, possibly three.

Noll (13), in a more extensive study of oats, found the "F_1 plants to be potentially as early or earlier than the early parent," and that the "F_2 population began heading with the early parent or earlier in crosses in which the parents were unlike in earliness, and earlier than the parent in the crosses in which the parents were alike in earliness."

Biffen (1) was one of the first to report on the inheritance of time of maturity in wheat. He studied time of ripening in a cross between an early Polish and a late Rivet wheat, and concluded that earliness and lateness are inherited independently of the other characters. The F_1 ripened near the date of ripening of the late parent.

Freeman (8) studied date of heading in crosses between a durum wheat (Algerian Macaroni) and the common white wheat Sonora, and between two common wheats, Red Algerian Bread and Early Baart. While date of heading in F_1 was not determined, he found that the average date of first heading in both the F_2 and F_3 progenies was intermediate but nearer to that of the late parent. In the crosses of macaroni and bread wheats the range in date of heading extended beyond that of the late parent. He concludes that the date of heading is governed by three or more Mendelian factors.

Thompson (14, 15, 16) studied the period of ripening in a number of spring wheat varieties. Crosses were made between individuals showing all possible degrees of maturity. In this way it was hoped that conclusions regarding hereditary differences between extreme varieties which might be reached by means of direct crosses could be checked by conclusions drawn from adding up differences between intermediate points. F_1 plants matured with the late parents, while the range in F_2 extended in all cases at least as far, in either direction, as the means of the two parents. In some cases F_3 families were obtained which were earlier than the early parent. He concluded that on the basis of a multiple determiner hypothesis of blending inheritance the results fail to explain satisfactorily the results as a whole, though they may explain the results of each individual cross.

Bryan and Pressley (2) crossed Sonora and Turkey wheats. They found the F_1 material heading almost exactly intermediate between the two parents. The F_2 generation extended over a range slightly exceeding that including both parents. In the F_3 and F_4 generations they were able to establish early, intermediate, and late homozygous races.

In a cross between Sunset and Marquis wheats Florell (7) found a segregation of early and late plants in the F_2 generation in the ratio of 3.07 early to 0.93 late. He explained this on a basis of difference in one allelomorphic pair of factors, with possibly a number of minor modifying factors. As a criterion of earliness he used the date at which the first head of each plant emerged from the sheath.

Clark (4) reported work on a cross between Kota and Hard Federation. He found few strains in F_3 as uniform in time of heading as the parents. He concluded that earliness, as determined by date of heading, was dominant over lateness. In 1926 he reported on maturity studies in crosses between Marquis and Hard Federation. His investigations were conducted during the heading, ripening, and fruiting periods. He found that early heading was partially dominant in F_2. Time of ripening of the hybrids was almost intermediate between the parents. Transgressive inheritance for lateness was shown in the F_3.

MATERIAL

For the investigation herein reported six varieties of spring wheat were used, *viz.*, Dicklow, Marquis, Federation, Reward, Prelude, and Master. The three first-named varieties were furnished by the Department of Plant Breeding at Cornell University. A detailed description of them is given in Bulletin 1074 of the U. S. Department of Agriculture. The other three sorts were obtained from L. H. Newman, Dominion Cerealist of the Dominion of Canada Experimental Farms, as three of their earliest varieties, by Dr. H. H. Love of Cornell University. A description of these varieties is found in Bulletin 11, new series, of the Dominion of Canada Department of Agriculture.

Table 1 shows the distribution of period of heading for the different parent varieties at Ithaca, N. Y., in 1925 and 1926. Table 2 gives the mean number of days required from time of planting to the appearance of the tip of the first head above the sheath on each plant. The greatest difference in the means of the parents of any cross in 1925 was 16.88 days, the mean for Dicklow being 73.15 days and the mean for Master 56.27 days. The smallest difference in parents of any cross for the same year was 5.11 days. This was between Federation, with a mean of 63.72 days, and Reward, with a mean of 58.61 days. The parents in the other crosses were intermediate between these two extremes. The totals given for each variety include all of the parents for the various crosses grown. The parents for each cross are shown in the F_2 tables.

METHOD OF PROCEDURE

The present investigation was begun in the winter of 1923–24. Since the varieties of wheat used varied considerably in date of maturity, they were divided for convenience into an early and a late group. Dicklow, Marquis, and Federation were classed as late, while Reward, Prelude, and Master were classed as early. Each of the late varieties was crossed with each of the early varieties and, in addition, Dicklow and Marquis were crossed, making 10 crosses in all. Some of the crosses were made in the greenhouse during the winter of 1923–24 and the remainder were made in the field the following summer. Part of the seed for the F_1 plants was grown in the greenhouse during the winter of 1924–25 and the remainder was held to plant with seed for F_2 plants in 1925. In this way, parents, F_1, and F_2 plants could be grown at the same time for comparison, and a supply of seed for F_2 plants could also be obtained Thus, in 1926, it was possible to compare parents, F_2, and F_3 material.

In order to obtain seed from the greenhouse early enough for spring planting, artificial light was used. No data from the greenhouse plants were taken since the artificial conditions existing there would not be comparable with field conditions.

In 1925, the seed was planted in the field on April 16. The planting was made in 5-foot rows and spaced at the rate of 30 seeds per row. The date on which the tip of the first head on each plant emerged

TABLE 1.—*Heading periods of parent varieties.*

Variety	Number of days from planting to heading																										
	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79–88	Total
1925																											
Dicklow													1		1	3	30	58	139	71	67	24	13	9	7	25	448
Marquis										7	58	98	106	50	26	5	4	4	4	1	1	1					365
Federation								3	17	287	111	76	15	8	4	1	1	2				1					526
Reward			9	60	117	101	62	6	8	6																	369
Prelude	6	99	115	148	54	12																					434
Master	4	220	75	148	62	13	11	4																			537
1926																											
Dicklow																	3	7	30	49	49	33	24	26	10	13	244
Federation										1	13	19	62	49	29	8	11	2			1		1		1		197
Reward					1	49	32	84	31	5	4	1				1											208
Prelude	6	36	51	81	57	24	4	2	1	1		1															264
Master	3	20	17	30	50	30	14	10	5	1	2																182

TABLE 2.—*Showing means and coefficient of variability for parent varieties and the F_2 generation for 1925 and 1926, and the means for the F_1 generations for 1925, with probable errors.*

Variety or cross	Number of plants		Mean and P. E.		C. V. and P. E.	
	1925	1926	1925	1926	1925	1926
Dicklow	448	244	73.15±.09	74.63±.11	3.70±.08	3.34±.10
Marquis	365		65.91±.06		2.62±.07	
Federation	526	197	63.72±.04	66.85±.09	2.04±.04	2.84±.10
Reward	369	208	58.61±.05	60.67±.06	2.24±.06	2.22±.07
Prelude	434	264	56.42±.04	57.01±.06	1.94±.04	2.63±.08
Master	537	182	56.27±.04	57.94±.10	2.40±.05	3.34±.12
			F_1 Generation			
Dicklow x Marquis	11		66.18±.35			
Dicklow x Reward	8		62.62±.16			
Dicklow x Prelude	12		62.33±.42			
Dicklow x Master	16		61.81±.35			
Marquis x Reward	9		62.11±.18			
Marqis x Prelude	12		58.33±.39			
Marquis x Master	13		59.77±.23			
Federation x Reward	25		61.72±.19			
Federation x Prelude	10		58.80±.15			
			F_2 Generation			
Dicklow x Marquis	298		67.88±.13		5.08±.14	
Dicklow x Reward	200		65.43±.14		4.36±.15	
Dicklow x Prelude	263	396	63.36±.12	65.44±.10	4.56±.13	4.74±.11
Dicklow x Master	515	338	64.28±.10	65.90±.10	5.27±.11	4.08±.10
Marquis x Reward	182		63.39±.13		4.13±.15	
Marquis x Prelude	195		61.47±.10		3.45±.12	
Marquis x Master	403		61.16±.09		4.33±.10	
Federation x Reward	315	394	60.90±.07	64.33±.08	3.10±.08	3.51±.08
Federation x Prelude	556		59.52±.06		3.33±.07	

from the top of the sheath was used as a criterion of earliness. Each day during the heading period the plants were tagged with small white tags bearing the date as each head appeared. In 1925 data for date of heading and for other characters were assembled after harvest. In 1926, the data were taken directly in the field.

In 1926 methods similar to those followed in 1925 were used, with the exception that the seeds were spaced at the rate of 20 seeds per row to facilitate tagging of the plants.

ENVIRONMENTAL CONDITIONS

It is quite evident that other than genetic factors play an important part in determining the date of maturity of wheat. Thompson (16) states that in 1920 the growing period for most varieties was 35 to 40 days shorter than it was in 1918, but other seasons showed very little difference. There seemed to be no appreciable difference in the length of the growing period for wheat at Ithaca in 1925 and 1926. The 1926 season, however, was a few days later, as is seen in Table 2 by comparing the means of the parents for the two years. It will also be seen in Tables 12, 13, and 14 that the 1925 parents are always earlier than the means of their F_3 progenies. In general, the varieties hold the same relative position with regard to each other during both years.

On some dates there seems to be a dropping off in the normal rate of heading. Examples of this are the 61st and 62d days in 1925 and the 63d day in 1926. The meteorological records for these periods show cold, or cold and stormy, weather.

HEADING PERIOD

In dealing with large numbers of individuals it is difficult to find any particular stage in the life of the wheat plant which can serve as an exact measure of earliness. The heading period is probably less affected by environmental conditions than is the ripening period and is thought to be a better index of time of maturity in an inheritance study. While this period may be used as a close approximation, it cannot be relied upon for too close distinction. Plants vary somewhat in the stage of maturity when the tip of the heads emerge from the sheath. Also, the time of day when a plant is examined often determines whether it shall be tagged then or left until the next day. In general, however, the heading date seems to be a fairly good index of maturity.

1925 RESULTS

F_1 GENERATION

As already stated, F_1 plants of all crosses were grown in the field for comparison with other plants. These F_1 plants were the result

TABLE 3.—*Frequency distributions of parents, F_1, and F_2 progenies of Marquis x Dicklow cross, expressed in number of days from planting to heading.*

Cross	Number of days from planting to heading																							
	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84–88	Total
19A																								
Marquis..........		1		9	17	4																		31
Dicklow..........									1	7	15	6	4		2									35
F_1..............				5	4		1			1														11
F_2........... ...	1	3	25	41	41	33	37	24	32	6	11	5	3	2		5				1	1	2	1	274
19B																								
Marquis..........		1		9	17	4																		31
Dicklow.....								1	2	10	12	5	3	1					1					35
F_2.........		1	1	2	6	4		3	3	1		2		1										24
Total F_2, 19A, 19B...	1	4	26	43	47	37	37	27	35	7	11	7	3	3		5				1	1	2	1	298
Marquis[a]....... ...		7	58	98	106	50	26	5	4	4	4	1	1	1										365
Dicklow[a]..........					1		1	3	30	58	139	71	67	24	13	9	7	7	4	5	2	2	5	448

[a] These frequencies are for the total plants of these varieties grown.

TABLE 4.—*Frequency distributions of parents, F_1, and F_2 progenies of Dicklow x Reward cross, expressed in number of days from planting to heading.*

Cross	Number of days from planting to heading																									
	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80–88	Total
Reward x Dicklow, 6B																										
Reward		9	7	5	2			1																		24
Dicklow															1	3	9	6	4	4	1		2		3	33
F_2				4	7	9	9	27	18	21	18	8	5	4	3				1			1			1	136
6C																										
Reward		11	4	4	1		1	1																		22
Dicklow															1	3	9	6	4	4	1		2		3	33
F_2						2	3	1	2	1	3	1			1	1			1							16
Dicklow x Reward, 5B																										
Dicklow															1	7	15	6	4		2					35
Reward		7	25	4	3	1																				40
F_2					3	2	7	9	4	6	3	8		3			2		1							48
F_1						1	1	6																		8
Total F_2 6B, 6C, 5B				4	10	13	19	37	24	28	24	17	5	7	4	1	2		3			1			1	200
Dicklow[a]											1		1	3	30	58	139	71	67	24	13	9	7	7	18	448
Reward[a]	9	60	117	101	62	6	8	6																		369

[a] These frequencies are for the total plants of these varieties grown.

TABLE 5.—*Frequency distributions of parents, F_1, and F_2 progenies of Dicklow x Prelude cross, expressed in number of days from planting to heading.*

Cross	Number of days from planting to heading																							
	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77–88	Tota
Prelude x Dicklow																									
4B																									
Prelude		3	11	5	1	1																			21
Dicklow																		1	9	7	9	2	1	6	35
F_2						1	3	3	2	6	1	1	1		1					1					20
4C																									
Prelude		11	8	6	3	2																			30
Dicklow																	1	3	9	6	4	4	1	5	33
F_2				1	2	4	27	21	19	37	35	22	13	4	1		4		1						191
4D																									
Prelude		2	11	15	1																				29
Dicklow																		2	15	8	7	1		2	35
F_2								1	3	6	7	7	3	4		4		1						1	37
Dicklow x Prelude																									
3B																									
Dicklow																			8	3	8	2	2	3	26
Prelude		2	5	11	5																				23
F_2						1	3	2		4	1	1	1	1	1										15
F_1							4	2	2	2					2										12
Total F_2																									
4B, 4C, 4D, 3B				1	2	6	33	27	24	53	44	31	18	9	3	4	4	1	1	1				1	263
Dicklow[a]													1		1	3	30	58	139	71	67	24	13	41	448
Prelude[a]	6	99	115	148	54	12																			434

[a] These frequencies are for the total plants of these varieties grown.

TABLE 6.—*Frequency distributions of parents, F_1, and F_2 progenies of Dicklow* x *Master cross, expressed in number of days from planting to heading.*

Cross	Number of days from planting to heading																										
	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79–88	Total
Master x Dicklow																											
2B																											
Master		1	3	7	3	2																					16
Dicklow																	1	3	8	4	8	4	3	4		6	41
F_2					1	1	6	5	10	27	29	23	16	4	7		1	4	2	2		3				1	142
2A																											
Master		20	3	5			1																				29
Dicklow																	4	10	12	4	2					1	33
F_2			1	1		1	24	9	17	44	46	21	16	11	11	6	1	2		2	2					2	217
Dicklow x Master																											
1D																											
Dicklow																	1	7	15	6	4		2				35
Master		13	6	7	1																						27
F_2			1	1	1	2	19	8	18	38	18	13	8	5	6		7	5	2	3		1					156
F_1							6	2	3	3	1				1												16
Total F_2																											
2B, 2A, 1D			2	2	2	4	49	22	45	109	93	57	40	20	24	6	9	11	4	7	2	4				3	515
Dicklow[a]													1		1	3	30	58	139	71	67	24	13	9	7	25	448
Master[a]	4	220	75	148	62	13	11	4																			537

[a] These frequencies are for the total plants of these varieties grown.

TABLE 7.—*Frequency distributions of parents, F_1 and F_2 progenies of Marquis* x *Reward cross, expressed in number of days from planting to heading.*

Cross	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	Total
Reward x Marquis, 18B																							
Reward		1	7	6	8	1	1	1															25
Marquis										7	7	5	1	2	1	2	1						26
F_2				2	11	19	18	29	19	8	5	2		2		1	1						117
Marquis x Reward, 17A																							
Marquis										3	12	4	3										22
Reward			1	5	13	1	3																23
F_2						6	13	12	12	9	5	3	1			1		1		1		1	65
F_1						3	2	4															9
Total F_2, 18B, 17A				2	11	25	31	41	31	17	10	5	1	2		2	1	1		1		1	182
Marquis[a]								7	58	98	106	50	26	5	4	4	4	1	1	1			365
Reward[a]	9	60	117	101	62	6	8	6															369

[a] These frequencies are for the total plants of these varieties grown.

Table 8.—*Frequency distributions of parents, F_1, and F_2 progenies of Marquis x Prelude cross, expressed in number of days from planting to heading.*

Cross	Number of days from planting to heading																						
	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	Total
Prelude x Marquis, 16A																							
Prelude		5	8	14	3	2																	32
Marquis											2	6	10	8	1								27
F_2						7	8	9	6	7		4	2	1	1								45
Marquis x Prelude, 15D																							
Marquis											13	6	4	2	2		1		1				29
Prelude		2	6	4	1																		13
F_2					5	21	35	21	7	25	9	5	1		1								130
15B																							
Marquis										4	12	10	1		1						1		29
Prelude		3	4	11	8																		26
F_2						1	3	3	2	8		1		1	1								20
F_1				4	4	3				1													12
Total F_2, 16A, 15D, 15B					5	29	46	33	15	40	9	10	3	2	3								195
Marquis[a]										7	58	98	106	50	26	5	4	4	4	1	1	1	365
Prelude[a]	6	99	115	148	54	12																	434

[a] These frequencies are for the total plants of these varieties grown.

TABLE 9.—*Frequency distribution of parents, F_1, and F_2 progenies of Marquis x Master cross, expressed in number of days from planting to heading.*

Cross	Number of days from planting to heading																							
	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76–80	Total
Master x Marquis,																								
14A																								
Master..........	1	16	5	4																				26
Marquis.........												5	9	8	3	1		1						27
F_2............				1	7	24	24	30	4	19	8	9	2	1		1	2	1		2			1	136
14C																								
Master..........			4	6	3	1	1																	15
Marquis.........											4	13	9	2	1		1							30
F_2.............				1	4	7	5	9	1	4	3	1												35
Marquis x Master																								
13B																								
Marquis.........											1	12	10	1	1			1						26
Master.........		16	2	4	4																			26
F_2.............		1		4	11	39	60	44	35	19	6	3	2	4	2			1	1					232
F_1.............			1			1	10		1															13
Total F_2, 14A, 14C, 13B		1		6	22	70	89	83	40	42	17	13	4	5	2	1	2	2	1	2			1	403
Marquis[a]...........										7	58	98	106	50	26	5	4	4	4	1	1	1		365
Master[a]............	4	220	75	148	62	13	11	4																537

[a] These frequencies are for the total plants of these varieties grown.

TABLE 10.—*Frequency distributions of parents, F_1, and F_2 progenies of Federation x Reward cross, expressed in number of days from planting to heading.*

Cross	Number of days from planting to heading																				
	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	Total
Federation x Reward																					
11B																					
Federation								16	2	3	1					1					23
Reward			8	12	15	1	2	1													39
F_2			4	11	10	12	5	2	3	1											48
11E																					
Federation							3	12	4	6										1	26
Reward	1	2	11	8	4																26
F_2		2	12	48	73	39	35	23	25	7	1	1	1								267
F_1					8	3	4	8	2												25
Total F_2, 11B, 11E		2	16	59	83	51	40	25	28	8	1	1	1								315
Federation[a]						3	17	287	111	76	15	8	4	1	1	2				1	526
Reward[a]	9	60	117	101	62	6	8	6													369

[a] These frequencies are for the total plants of these varieties grown.

TABLE 11.—*Frequency distributions of parents, F_1, and F_2 progenies of Federation x Prelude cross, expressed in number of days from planting to heading.*

Cross	Number of days from planting to heading																						
	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	Total
Prelude x Federation																							
10A																							
Prelude		10	4	4	1																		19
Federation										26	6	1			1								34
F_2				2	4	11	10	5	4	4				1									41

Federation x Prelude																							
9A																							
Federation										20	6	5		1	1	1							34
Prelude		7	14	8	2																		31
F_2		1	2	13	52	34	30	5	6	6	1	1		1					1				153
9B																							
Federation										10	10	11	3				1						35
Prelude		16	4	6	2																		28
F_2				2	6	13	6	7	4	1		1											40
9E																							
Federation									1	24	7	3											35
Prelude		5	7	8	5																		25
F_2		1	2	26	49	40	61	15	10	7	3	4											218
9C																							
Federation										18	5	1			1								25
Prelude		16	4	6	2																		28
F_2				5	12	15	16	7	2	1	3	1						1					63
9D																							
Federation										18	5	1			1								25
Prelude			7	5	9	3																	24
F_2				1	7	9	10	2	3	3	5		1										41
F_1					4	5		1															10
Total F_2, 10A, 9A, 9B, 9C, 9E, 9D		2	4	49	130	122	133	41	29	22	12	7	1	2				1	1				556
Federation[a]								3	17	287	111	76	15	8	4	1	1	2				1	526
Prelude[a]	6	99	115	148	54	12																	434

[a] These frequencies are for the total plants of these varieties grown.

of crosses between the same varieties as were used for the F_2 plants with which they were compared. In a few cases only were they from the same parents. While the numbers are small, it can be seen from the several F_2 tables that the F_1 plants are intermediate between the two parents, with a tendency toward the early parent.

F_2 GENERATION

Tables 3 to 11, inclusive, show the F_2 distributions in 1925. The distributions for 1926 will be shown later with the F_3 material.

In each of the F_2 tables are given the frequency distributions of the parents, the F_1, and F_2, and the distribution of all of the plants of the parent varieties. The total of the parent varieties grown is included because the larger numbers give a better idea of the normal range and distribution.

The tables show a wider range in distribution of F_2 frequencies than is found in either parent. The tendency is to approach the extremes of both parents. In some cases these extremes are exceeded, while in other cases they are never reached. Where the parents differ greatly there is less tendency for the F_2 distributions to reach the parental extremes. The majority of the individuals lie intermediate between the parents, and the various distributions tend to approach a normal frequency distribution. The number of F_1 individuals is insufficient for accurate comparison with the parents and the F_2 frequencies. The indications are, however, that they lie intermediate between the two parents and that the variation is not so great as in the F_2 frequencies. There is a noticeable tendency for both the parents and the F_2 material to spread toward the upper end of the range.

DICKLOW CROSSES

Marquis and Dicklow are the two latest-maturing varieties used. The mean number of days from planting to heading for Dicklow is 73.15 days and for Marquis 65.91 days. The earliest Marquis plant headed on the 63d day and the earliest Dicklow plant on the 70th day. The total Dicklow distributions, however, show one plant heading as early as the 66th day. There were 298 F_2 plants of this cross grown. They ranged from 62 to 86 days, exceeding the extreme of the early parent and closely approximating that of the late parent.

Reward is the latest of the early varieties. The mean number of days from planting to heading in 1925 was 58.61. The eight F_1 plants are intermediate in date of heading. While the F_2 covers a wide range, from 59 to 82 days, it does not reach either of the parental extremes.

The mean number of days from planting to heading for Prelude and Master is practically the same, Prelude being 56.42 days and Master 56.27 days. The F_2 individuals from these varieties are also very similar. There were grown 263 F_2 plants of the cross between Dicklow and Prelude and 515 plants of the cross between Dicklow and Master. In neither progeny were the extremes of either parent reached, although the range of distribution was very great, extending over a period of from 56 to 85 days from time of planting to time of heading in the cross between Dicklow and Master. In this case there was a close approach to the extreme of the late parent.

MARQUIS CROSSES

Tables 7 to 9, inclusive, give the results of the crosses between Marquis and the three early varieties. In none of these crosses is the extreme range of the early parent reached, although it is closely approached in the cross between Marquis and Master. Both the F_2 distributions of the cross between Marquis and Reward and between Marquis and Master exceed slightly the extreme of the late parent. An interesting fact in connection with the cross between Marquis and Reward is that the Reward variety is a selection from a cross between Marquis and Prelude. It apparently has lost some of the factors for earliness of the Prelude variety.

FEDERATION CROSSES

The results of the cross between Federation and Reward and between Federation and Prelude are given in Tables 10 and 11. Dwarf plants, all late in maturing, appeared in the F_2 generation in the cross between Federation and Master. The earliness study with this cross was discontinued on account of this abnormal condition.

The cross between Federation and Reward did not quite reach the extremes of either the early or the late parent, while the extreme of the late parent was exceeded and the extreme of the early parent nearly reached in the cross between Federation and Prelude.

F_2 AND F_3 RESULTS IN 1926

On account of the large number of plants it was impossible to carry all of the F_2 material through the F_3 generation. Three crosses were selected for 1926 planting, Dicklow x Master, Dicklow x Prelude, and Federation x Reward. An F_2 generation of each of these crosses was also grown, with results very similar to the 1925 results. Each cross showed a wide range of distribution, but in no case was the extreme of the parental types reached, although there was a close approximation in the Federation x Reward cross.

The F_2 and F_3 results are shown in Tables 12, 13, and 14. The

TABLE 12.—*Showing the distribution of F_3 families of the Dicklow x Prelude cross.*

Row	1925 F_2	Number of days from planting to heading																								Total	Mean
		54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78–87		
Prelude		6	36	51	81	57	24	4	2	1	1		1														264	57.01±.06
246	58					8	5	5	8	5	2	3	1														37	60.54±.22
252	59					1			6	11	3	5	4	2	2				1								35	63.20±.26
261	58					3	3	6	12	9	2	3	5	1	2	1		1					1				49	62.39±.31
288	60					2	2		12	11	8	9	4	1	3	1	1	1									55	62.95±.22
243	57						4	10	13	9	2	2		1													41	61.15±.15
251	59						1		3	6	3				1												14	62.14±.30
254	59						2	1	8	28	11	9	4	4	1	1	1										70	62.84±.15
268	60						3	3	9	9	8	13	11	8	2												66	63.29±.17
284	60						1		7	16	11	12	5	5	3												60	63.25±.15
376	63						1	3	2	13	8	11	10	5	5	1	1								1		61	64.00±.23
230	62							1	5	13	14	13	12	5		2	1	1									67	63.73±.16
304	61							3	9	10	5	9	9	2	2	1	3		1	3		1		1		2	61	64.93±.38
276	60							1	6	23	9	10	8	4	1												62	63.06±.13
248	59								4	19	3	10	5	2	3	1	1										48	63.46±.19
258	59								6	7	11	11	6	2	1				1						1		46	63.78±.27
264	59								2	2	11	12	20	14	6				1								68	64.76±.13
296	61								3	7	9	9	8	5	2		2					1			1		47	64.53±.29
352	64								1			6	10	5	14	8	9	2	1	1							57	66.86±.18
404	68								1			1	7	9	19	16	10	2	2		1	2					70	68.46±.17
272	60									20	13	14	9	3	4	2	1				1						67	63.94±.17
292	61									5	3	16	22	5	4								1				56	64.75±.17
300	61									1	3	3	13	15	7	7	6	2		2	1			1			61	66.72±.21
308	61									2	6	16	20	20	1	2	1	1									69	65.04±.12
316	62									10	4	14	11	13	3	6	1					1					63	64.68±.18
324	62									1	2	9	16	20	11	9	4		1								73	66.03±.13

		Number of days from planting to heading																												
		59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86		
332	62				2	2	12	25	9	11			1	1	1				2											66	65.74±.21
336	64				8	7	17	12	4	5	2	2	2																	59	64.71±.18
340	64				1	2	12	12	9	20	5				2			1				1								65	66.28±.22
344	64				1	4	14	13	15	18	2	2					1	1												71	65.83±.17
356	64				1	2	2	12	8	16	11	10	3	1	1							1								68	67.15±.20
384	66				1				4	7	4	15	11	3	2	1		1			1									50	69.10±.25
396	67				1	6	11	6	6	12	10	6	4																	62	66.26±.18
424	72				1	1	2	1																						5	63.60±.31
328	62					8	4	24	14	7	3	4			1						1		1							67	66.01±.23
364	63					3	1	13	15	21	2	1	2			1			1											60	66.48±.18
372	63					3	6	7	10	14	9	5	4	1	3	1	1	1		1			1							67	67.60±.26
420	69					1		1	2	10	19	9	6	1	1			1			1									52	68.44±.20
431	70					1	1	3	2	17	7	2											1							34	67.26±.24
360	63						6	16	9	15	8	1	7	1	1															64	66.70±.16
380	66						1	3	6	12	7	7	8	2	1	1				1	1	1								51	68.37±.28
400	67						2	8	9	10	19	4	13	2	2	1					1				1					72	68.17±.22
425	71						1	1	1	1																				4	?
433	70						1	2	1	2	3	3	2																	14	67.25±.33
368	63							2	12	12	12	8	5		3	1			1	1										57	68.18±.21
430	70							2	1		5	4	4	1		2														19	68.89±.33
388	66								1	10	8	14	11	5	3			1	2		2									57	69.65±.23
413	69								1	1	10	11	13	6	9	5	3	2		1	2									64	70.72±.21
411	68									3	5	4	1	5	4	2	4			1	1									30	70.90±.37
417	69									1	4	14	15	5	4	3	4	1				2								53	70.68±.23
423	69									6	3	1	4					1												15	68.67±.36
408	68										1	6	17	10	6	2	1		1	1										45	70.68±.17
1926	F_2	3	4	12	45	34	62	60	53	55	26	12	9	5	3	3	1	3	1		2	3								396	65.38±.10
Dicklow													3	7	30	49	49	33	24	26	10	5	3			2		1	2	244	74.63±.27

TABLE 13.—*Showing the distribution of F_3 families of the Dicklow x Master cross.*

Row	1925 F_2	Number of days from planting to heading																									Total	Mean
		54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78–87		
Master		3	20	17	30	50	30	14	10	5	1	2															182	57.94±.10
20	58					4	9	11	13	10	4	7	5		1	1	2	1									68	61.82±.22
24	59					1		2	5	5	10	14	4	4	11	5	1			1							63	64.46±.22
29	59					4	16	4	15	15	6	2	1		3		1										67	61.22±.19
49	60					3	3	1	12	13	7	5	2	1									1				48	62.10±.17
12	57						3	4	8	11	5	7	4	1	6		2	1				1					53	63.40±.25
33	59						4		9	15	2	10	15	3	1	1	1	1			1						63	63.51±.22
37	60						1	2	6	16	3	12	7	9	2	3	2	2	1	1		1	2			1	71	64.86±.31
53	60						1	1	4	7	7	5	13	5	3	1											47	63.87±.20
77	61						1	3	8	6	14	4	3	3	1	3	2			1							49	63.49±.26
97	62						1		1	10	7	11	12	7	4	1							1			2	57	64.96±.36
15	57							3	4	5	4	3	6	1	1			1									28	63.25±.29
28	59							1	3	7	1	6	3														21	62.81±.22
57	60								3	8	11	11	10	3	2	1		1									50	63.92±.17
129	64								1	3	5	6	7	4	5	2	1		2		1	2		1	2	1	43	66.95±.47
5	62									2	5	12	22	12	5	3	2										63	65.17±.13
61	61									1	1	9	13	14	11	1	4	1	1	1	1	3					61	66.54±.23
65	61									1	1	7	20	20	4	2							1			1	57	65.79±.21
69	61									8	4	7	13	9	4	4	2	4	2	1		1			1		60	65.97±.27
81	62									10	6	11	6	8	10	3	3	2	2	1						1	63	65.62±.26
85	62									13	7	20	15	10	4												69	64.20±.12
89	62									1		6	19	15	20	6	4	5									76	66.38±.13
113	64									1	1	9	10	20	8	6	3	2	3		1				1		65	66.54±.20
125	64									2	1	2	10	15	15	8	4	1		2	4				2	1	67	67.43±.26
184	73									3	1	3	3	5			1								1	1	18	66.17±.72
103	75									1	2	3	2	5	1	1											15	65.00±.28

		Number of days from planting to heading																										
		59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83–87		
105	64					1	7	9	16	21	7	3								1							65	66.45±.16
117	64					1	1	11	20	11	13	3	2			1											63	66.71±.14
121	64					1	2	3	13	12	10	6	7	4	2	2	2	2									66	68.24±.22
173	73					1	3	4	11	13	10	4	1	2													49	66.94±.16
187	74					1	2	3	2				1														9	65.11±.42
93	62						7	14	14	14	7	4	4	1													65	66.51±.14
9	56							4	6	12	10	3	2	4	1	5	2		1								50	68.64±.26
109	64							9	26	17	12	5	1	2	2					1					1		76	67.32±.20
133	67							1	8	11	12	3	4	4	3			3	4	3					1		57	69.74±.34
145	68							1	1	4	10	7	11	3	3	2	1	1	1	1							46	69.76±.24
137	67								15	8	11	7	3	3		1	1		1							1	51	68.39±.30
156	71								1	4	13	20	12	3		1											54	68.96±.11
196	79								2		2	2		1	1												8	68.63±.48
169	72									4	1	3	1	2	1		1										13	69.31±.40
185	74										1		1		4	3	6	2	6	3	2	2					30	74.67±.31
159	71											2	7	4	3	5	7		1	1	2	1				3	36	73.67±.45
162	72											1	3	7	3	8	3	4	5	6	1	2				4	47	74.77±.38
170	72											1	1	3	3	4	5	2	7	6	4	2				1	39	75.15±.35
181	73											1	10	5	1	2	1			5		2	1			1	29	73.21±.49
176	73												1			1	1		3	5	1	5			1	2	20	77.97±.51
189	75												2	2	4	8	8	5	7	11	5	2		4	1	2	61	75.82±.28
188	75													1	4	4	4	1	3	5	2	1	2	1			28	75.39±.29
194	75														3		3	3	3	1	1	1					15	76.60±.79
197	85																	1	1	1					1		4	
1926	F_2	1	1	5	28	19	34	48	90	45	29	19	5	6		2	2	1				2		1			338	65.90±.10
Dicklow													3	7	30	49	49	33	24	26	10	5	3			5	244	74.63±.27

TABLE 14.—*Showing the distribution of F_3 families of the Federation x Reward cross.*

Row	1925 F_2	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	Total	Mean
		Number of days from planting to heading																					
Reward				1	49	32	84	31	5	4	1				1							208	60.67±.06
473	57	2	2	8	27	8	9	4	1	2												63	59.54±.14
477	57	3	4	12	9	3	9	2		2	1											45	59.31±.21
513	58		2	1	11	2	11	3														30	59.93±.17
489	58			1	10	11	19	11	2	5												59	60.93±.13
497	58			1		2	10	22	3	2	3				1							44	62.11±.17
505	58			4	13	7	24	5	2		1	1										57	60.53±.14
509	58			2	15	4	26	12	2	2												63	61.35±.11
519	60			1	1	1	16	26	6	11	7	3	1									73	63.56±.13
555	60			4	16	2	23	16	4	6	1										1	73	61.19±.18
480	61				4	2	13	13	3	6	4	1		1								47	62.17±.19
483	58				1	4	19	16	1	2	3						1					47	61.85±.18
493	58				5	1	18	16	9	13	1		1		2	1					1[a]	68	62.72±.26
501	58				1	4	13	19	6	6	3	1				1						54	62.07±.16
515	60				3	1	13	19	7	9	7	8	2	1								70	63.00±.16
535	60				1	1	16	22	9	4	5	4					1		1			64	62.74±.19
547	60				1		6	23	4	18	4	3	2		1							62	63.16±.15
567	62					2	12	22	11	13	4	1										65	62.57±.11
486	58						2	12	6	12	7	3	4	1	1							48	63.96±.18
539	60						2	17	13	14	5	5	4	1	1							62	63.73±.15
575	62						1	15	22	22	13		4									81	63.73±.10
580	64						1	7	11	17	6	1	4		2							49	64.04±.16
604	64						1	5	9	17	12	13	10	4							1	72	65.01±.16
639	65						2	5	4	5	1		1									18	63.11±.23

		Number of days from planting to heading																							
		61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82		
527	60		4	11	14	15	8	3	1	1		1	1		1									60	64.92±.19
543	60		1	5	17	7	7	14	5	3	1	2	1	1										64	66.00±.20
551	64		1	4	11	15	12	10	9	2	1		1							1		1		68	66.28±.25
563	62		1	9	23	17	16	1	1				1											69	64.77±.12
571	62		3	17	22	8	11	3	2															66	64.36±.12
608	64		1		1	4	13	11	11	8	10		7	2		1	1							70	68.31±.21
612	64		3	6	19	6	17	5	2		2	1												61	65.15±.16
625	65		1	1	11	16	16	10	4	5	2		1	1										68	66.13±.16
559	62			2	5	6	18	10	7	2		2	1	1		1								55	66.73±.21
592	64			3	27	7	12	5	1	1			1				1							58	65.24±.19
596	64			1	17	11	13	7	1	4														54	65.50±.14
600	64			1	6	10	27	8	12	4		2	1											71	66.49±.14
616	64			1	3	11	24	17	14	2							1							73	66.56±.13
636	65			2	4	7	10	7	5	4	1			1					1					42	66.74±.27
647	67			3	7	2	9	2		1														24	65.17±.20
579	64				1	1	1	2	2	1	2				2			2				1	1	16	71.15±.92
584	64				6	8	14	18	11	2	4	3			1									67	66.97±.16
623	65				2	3	7	4	2	3	1	2												24	67.00±.27
633	65				2	4	15	7	6	6	5	1	2						1					49	67.59±.23
640	65				2	5	11	5	3	1	1		1											29	66.52±.21
620	65						2	11	11	6	7	1	1		1									40	68.45±.17
642	65						1	6	8	17	13	4		2	2			1		1	1			56	69.80±.24
1926	F_2	26	62	61	100	26	64	26	11	8	4	2	2	1				1						394	64.33±.08
Federation				1	13	19	62	49	29	8	11	2			1		1		1					197	66.85±.09

[a] This plant headed on the 81st day.

F_3 families are arranged in the order in which the first plant headed. With each family is given the number of days from planting to heading of the 1925 F_2 plants from which it originated. The means and probable errors of the F_3 families are also given. Not all of the F_3 generations were grown. The early and late extremes and part of the intermediate F_2 individuals were selected to grow for the F_3.

In a general way the time required between planting and heading of the F_3 families agrees with that of their F_2 parents. Nearly all degrees of earliness between the early and late parent are represented. In the case of the cross between Dicklow and Prelude none of the families reached the extreme of either the early or the late parent. In the cross between Dicklow and Master F_3 families were found as late as the late parent, but none were as early as the early parent.

The cross between Federation and Master produced some F_3 families earlier than the early parent as well as some later than the late parent. This was apparent not only from the dates of heading, but also at the time of maturity. The F_3 families differed greatly in range and variability. Some had a range as narrow as, or narrower than, the parents, while others covered nearly as wide a range as the F_2

DISCUSSION

From the results it is evident that this is a case of blended inheritance where a number of independent multiple factors are concerned. There were too few F_1 plants grown to determine their exact relation with regard to the parents and F_2, but it was quite evident both in the greenhouse and in the field that the F_1 generation was later than the early parent and earlier than the late parent. The means given in Table 2 show the F_1 to be intermediate with a tendency toward the early parent. The numbers, however, are insufficient to be significant. The means for most of the F_2 frequencies lie near the mid-point between the two parents. In the cross between Dicklow and Master, however, the mean is 5.5 days earlier. This may indicate incomplete dominance for at least part of the factors concerned with earliness. The fact that the later plants seem to be distributed over a wider range indicates that environmental conditions may be a factor in shifting the mean nearer to the late variety than would ordinarily be expected.

In comparing the F_2 distributions with their parents, a wider range and a greater variability for the F_2 is very evident. Tables 3 and 9, particularly, show this wide range. In all cases the coefficient of variability of the F_2 is greater than that of either parent. In the cross between Dicklow and Master, for example (Table 2), the F_2

has a coefficient of variability of 5.27, while the coefficient of variability of Dicklow, the most variable parent, is only 3.7. This indicates that segregation of genetic factors is taking place. The fact, however, that the greater number of individuals are intermediate between the two parents and that there is no apparent segregation into distinct early and late groups, indicates that this is not a simple case of Mendelian segregation.

It is difficult to draw conclusions from the F_2 data in cases of this kind, since individual selections, even when homozygous, represent a population which may extend over a considerable range. Thus, even in a case similar to that of the cross between Marquis and Prelude (Table 8), where the extremes of neither parent are reached, the F_3 generation may show that the parent types have been recovered and that the F_2 selection represented a population away from the extreme. As already stated, in only one cross, that between Dicklow and Master, was the extreme of the early parent reached or exceeded and in only three crosses, those between Marquis and Reward, Marquis, and Master, and Federation and Prelude, was the extreme of the late parent reached.

The results of the F_3 generation give a better idea of the genetic constitution of the F_2 population. These results furnish considerable evidence that earliness is controlled by a number of multiple factors. In the cross between Dicklow and Prelude neither parental extreme was reached, yet there appeared apparently homozygous families at almost every point between the parental extremes. Families 246, 276, and 308 (Table 12) are examples of this. This indicates that a number of genetic factors are concerned. That the parental extremes are not reached is probably due to the fact that the number of F_2 individuals was too small. All grades of variability between the parents and F_2 distributions are also apparent which may indicate different degrees of heterozygosity. The F_2 parent plants for families 424 and 425 were not normal plants, but each was small and spindling with only a single culm. Something had evidently interfered with their normal development so that the date of heading was not a true index to their genetic composition. The same thing is true of families 193 and 196 of the cross between Dicklow and Master (Table 13). Each came from a short, spindling plant with a single culm.

In the cross between Dicklow and Master the later parental type seems to have been recovered in a few cases. The numbers in some of these cases are very small and some of the plants are badly attacked by rust. General observation as the plants ripened, however, indicated that the late parental type had been reached. The fact that the early parental type had not been reached may be due to insufficient numbers where many factors are concerned, or to the action of some modifying factors. In this cross, as well as in the cross between Dicklow and Prelude, all degrees of range and variability are found. Compare, for example, families 85 and 97. The range for family 85 is from 62 to 67, which is narrower than either parent, while 97 shows a range similar to that of the F_2 distribution.

Table 14 shows the F_3 distribution of the cross between Reward and Federation. The results here differ from those of the other two crosses in that both parental extremes are exceeded. (See families 473, 477, and 513 for early extremes and families 620 and 642 for late extremes.) This is doubtless a case of transgressive inheritance. Federation, the later parent, evidently carries factors for earliness which the early parent does not carry. These are combined in the early families and the late allelomorphs in the late families. The combination of these in the early families and the combination of their later allelomorphs in the late families accounts for the two parental types being exceeded.

The data given indicate that earliness in the varieties studied is due to the presence of a number of independent multiple factors which have a cumulative effect. From the data it is impossible to determine the exact number of factors concerned or the value of the various factors. Even if it is assumed that all factors for earliness have the same value and respond alike to the same environment, large numbers and a long period of time would be necessary for even a close approximation of a definite factorial analysis.

In 1925 a positive correlation between height of plants and the number of days between planting and heading was observed in the cross between Federation and Master. The results showed a correlation coefficient of 0.394 ±.019.

OCCURRENCE OF DWARFNESS

In 1925 the cross between Federation and Master segregated for normal and dwarf plants in the F_2. The dwarfs were small, grass-like tufts ranging in height from a few inches to 8 or 10 inches. They were readily identified by their dark green color and their short, tuft-like appearance. They were all very susceptible to rust attack.

Table 15 gives the F_2 frequencies for 1925 and 1926. From this it will be seen that the results for both years would indicate a 13:3 ratio. This suggested the presence of a dominant dwarf factor with an inhibitor; the latter, when present in the dominant condition, preventing the appearance of the dwarf character.

To test this further, seed from each of the 52 dwarf plants was planted in the greenhouse in the winter of 1925–26. Some of the dwarf plants had produced very little seed and all of it was badly shriveled and in a very poor condition. Where there was a sufficient supply, five pots with four seeds per pot were planted from each dwarf plant. The results are shown in Table 16. It will be seen from the table that 29 of the 47 families producing plants segregated for normal and dwarf individuals. The normal plants could be distinguished from the dwarfs in the very early seedling stage, because of the very dark green color of the latter. Many of these dwarfs did not mature sufficiently to produce seed, but died soon after they had appeared above ground. The normal segregates had every appearance of a normal plant, some of them exceeding in height both of the original parents.

TABLE 15.—*F_2 segregation of normals and dwarfs in crosses between Federation and Master.*

Crosses	F_2 Plants Normals	Dwarfs	Total	Deviation from 13:3 ratio	Probable error
		1925			
Federation x Master					
7A	13	4	17	0.82	1.39
7E	25	3	28	1.68	1.78
Master x Federation					
8C	25	6	31	0.18	1.88
8D	186	39	225	3.18	5.00
Total 1925	249	52	301	4.43	5.85
		1926			
Federation x Master					
7D	33	3	36	3.75	2.02
Master x Federation					
8A	252	52	304	5.00	5.88
8B	186	42	228	0.75	5.09
Total 1926	471	97	568	12.86	8.16
Total 1925 and 1926	720	149	869	13.93	9.94

Of the 52 dwarf plants, 47 produced plants. Of these, 29 segregated for normals and dwarfs and 18 did not. If the previous hypothesis of a dominant dwarf with an inhibitor is assumed, the F_1 of a cross between Federation and Master would have the constitution DdIi, where D is the factor for dwarfness and I is an inhibitory factor which in the dominant condition prevents the appearance of dwarfness. The F_2 dwarf plants would then be of the genetic constitution DDii or Ddii, and these in the proportion of 2 Ddii to 1 DDii. It would be expected, therefore, that two-thirds of the 47 families would segregate for normals and dwarfs and one-third breed true for dwarfness. Twenty-nine segregating and 18 breeding true are very close approximations to this.

Where segregation took place a simple 3:1 type—three dwarfs to one normal—would be expected. The results show, however, 118 dwarfs to 70 normals, or an insufficient number of dwarfs. This is probably due to a lethal or weakened condition which has prevented the appearance of some of the dwarf plants. This is suggested by the fact that 42%, or 188 of the 445 seeds planted, produced plants where segregation took place, while only 34%, or 81 of the 239 seeds planted, produced plants where no segregation was found.

TABLE 16.—*F_3 families segregating for normals and dwarfs in 1925–26 and in 1926.*

Breeding behavior in F_3	Number F_3 families	Expected (Normals 6:7 ratio Dwarfs 2:1 ratio)	Deviation from expected ratio	Probable error
Normals breeding true.	107	119.54	12.54	5.00
Normals segregating for normals and dwarfs	115	102.46		
Dwarfs breeding true.	18	15.66	2.34	2.16
Dwarfs segregating for normals and dwarfs	29	31.34		

The normal segregates of the 1925 F_2 population were grown in the field in 1926. The results are shown in Table 16 with theoretically thirteen-sixteenths of the whole F_2 population represented. Of these six-sixteenths would be expected to segregate and seven-sixteenths to breed true. Of 222 families grown, 115 showed segregation for normals and dwarfs and 107 bred true The calculated expectancy is 102.46 segregating and 119.54 breeding true. This is a difference of 12.54, or 2.58 times the probable error, which is not a very good fit. However, in the light of the other evidence, the results can hardly be considered as differing significantly from the suggested hypothesis.

Clark (5), working with a dwarf apparently similar to the one here described, in a total of 224 families finds a difference of only 6 from the expected. In the families segregating there were a total of 2,012 plants, 649 of which were dwarfs.

There is yet but little evidence concerning the genetic constitution of the parents. Both Master and Federation have resulted from crosses in which Indian varieties of wheat were used. Most of the dwarf wheats have originated from the Indian wheats. In 1925 a cross between Master and dwarf was made and only one F_1 seed was produced. This was planted in the greenhouse with the dwarf seed in 1925–26, and produced a plant which unfortunately did not live past the seedling stage. It survived long enough, however, to manifest the dark green color and characteristic appearance of the dwarf seedlings growing in pots near it.

In a cross between dwarf and Federation made in the greenhouse in 1925–26 a few seeds were produced. The plants matured so late that it was not possible to plant them in the field until June 15. Three of the plants, although small due to such late planting, appeared to be normal plants.

While these results cannot be considered conclusive without being verified in further crosses, they suggest that the Federation parent was of the constitution DDII, while the Master parent had the constitution ddii.

Other crosses have been made and the work is being continued with the expectation of gaining further conclusive evidence.

SUMMARY

1. Results are reported on the inheritance of earliness in various crosses between six varieties of spring wheat.

2. The date when the tip of the first head of each plant emerged from the top of the sheath was used as the index of earliness.

3. Parents, the F_1, and the F_2 generations were planted the same day and grown for comparison in 1925. In 1926 a similar comparison was made between the parents, the F_2, and the F_3 generations.

4. The mean of the F_1 population was intermediate but nearer to the early parent than to the later parent. The means of the F_2's were intermediate or tended toward the early parent.

5. The F_2 was more variable than either parent and extended over a range approximating the combined range of both parents. The F_3 families showed almost all degrees of earliness within the limits of the parent varieties. In one cross neither extreme was reached, in another the extreme of the late parent only was reached, while in a third the extremes of both parents were exceeded.

6. The data indicate that earliness may be due to the action of a number of independent multiple factors having cumulative effect. From the evidence available, however, it is impossible to draw definite conclusions as to the exact number or value of the factors concerned.

7. Where the parental types are not recovered in F_2, it is probably due to insufficient numbers. Where the parental types are exceeded, there is evidently a case of transgressive inheritance.

8. In the cross between Federation and Master a positive correlation was found between number of days from planting to heading and the height of plant, the correlation coefficient being 0.394 ±.019.

9. The occurrence of dwarfs in the cross between Federation and Master is discussed. It is explained by assuming the interaction of

two pairs of factors, "D", a dominant factor for dwarfness, and "I", an inhibitor, which, when present in the dominant form, prevents the appearance of the dwarf character.

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SOME CAUSES OF THE INJURIOUS AFTER-EFFECTS OF SORGHUMS AND SUGGESTED REMEDIES[1]

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INTRODUCTION

The sorghums are a class of crops which, so far as their production is concerned, fit admirably into the agriculture of many sections of the United States. The advantages of high yields, drought resistance, vitality, and profitableness have recommended them to the farmer's consideration. Under many conditions, however, their culture has proved injurious to certain crops following and especially to the small grains. This injury has been so great under certain conditions as to overbalance in the minds of the farmers the many advantages of these crops. Though the yields of the sorghum crop itself may be high, the crop sequence of sorghum followed by a small grain may be much less profitable than an entirely different crop sequence which would not include any of the sorghums. Field tests have been reported from time to time showing the extent of injury to crops following sorghums. Comparisons have been made in most cases between yields of small grains following sorghums and yields of those crops following corn, though other crops have been used as test and comparison crops.

INJURY OF SORGHUMS TO SUCCEEDING CROPS

Ten Eyck and Shoesmith (20)[3] conducted crop sequence studies with corn and various other crops in Kansas from 1904 to 1906. They secured the lowest yields of corn where this crop followed kafir and sorghum.

Towle (21) at Sheridan, Wyoming, secured a slight depression in the yield of wheat following sorgo but apparently no depression in oats.

From 1909 to 1923 Brandon (1) at Akron, Colorado, secured smaller yields of oats following sorgo, milo, and kafir than from oats following corn. The average yields were, respectively, 7.8 bushels, 3.5 bushels, and 5.2 bushels less than the yield of oats following corn.

From 1916 to 1920 at Fort Hayes, Kansas, Cole and Hallsted (4) carried on two-year rotations in which corn and kafir were alternated with winter wheat. In one of the corn rotations the corn was spaced normally, while in the other the rows were spaced twice as far apart.

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[3] Reference by number is to "Literature Cited," p. 1110.

The same variation in spacing was carried on with the two kafir rotations. Wheat following kafir in both spacings yielded on the average less than wheat following corn. In the normal spacings the depression following kafir was 7.5 bushels, or 40% below that of wheat following corn. The yield of wheat following the doubly spaced kafir was 4.4 bushels, or 22% below that of wheat following corn doubly spaced. Incidentally, doubling the space between rows of the kafir and corn increased the yields of grain 4.4 bushels and 6.7 bushels, respectively, and decreased the yield of stover 1,121 pounds and 245 pounds, respectively. They further report that barley which is spring sown yields practically as well following kafir as following corn. However, kafir following kafir yielded only about two-thirds that following wheat.

Vinall and Getty (23) state that according to experiments in Alabama, Arkansas, Kansas, and Nebraska, corn, oats, wheat, and other crops yielded on the average 24.5 bushels per acre after corn and but 20.7 bushels after various sorghums.

Farmers of the Imperial Valley have been noticing for a number of years that small grains yielded rather poorly after the sorghums. In order to obtain a measure of the actual amount of injury and to arrive at possible causes, the Imperial Valley Experiment Station of the University of California has included milos in its crop rotation experiment since 1923. The injury thus shown is among the worst, if not the worst, that has come to the writer's attention. Table 1 gives the rotations, treatments, and yields secured at that station.

TABLE 1.—*Yields in pounds of threshed grain per acre from certain plats in the cereal rotation experiment at the Imperial Valley Experiment Station, University of California.*[a]

Plat	Summer treatment, 1923	Winter treatment, 1924	Summer treatment, 1924	Winter treatment, 1925
A	Fallow	Barley, 2,350	Fallow	Barley, 1,546
B	Fallow	Wheat, 1,465	Fallow	Wheat, 1,277
D	Milo	Fallow	Fallow	Wheat, 1,681
E	Milo	Wheat, 280	Milo	Wheat, 336
I	Milo	Fallow	Fallow	Barley, 2,554
J	Milo	Barley, 450	Milo	Barley, 604

[a] The writer wishes to express thanks to Mr. L. G. Goar for these and other data from the Imperial Valley Experiment Station.

It will be observed that the yields of wheat and barley following milo are but one-fifth to one-third what they are following nearly any other treatment.

In order to get some idea of the injury occurring in other parts of the state, questionnaires were sent out to county agents in the sorghum-growing regions of California. These disclosed that farmers recognize a decrease in yields of small grains following sorghums estimated from 10 to 50% below yields from small grains following crops or treatments other than sorghum. The greatest decreases occurred in the Imperial Valley. When the reports were arranged in the order of the decreases estimated by the county agents, the further north in the state the source of the report the less was the estimated decrease. There were hardly enough reports, however, to establish this point definitely.

In regard to the possible causes of the depression in yield two theories have been advanced, one that the sorghums use up a much greater amount of the available constituents in the soil, hence there would be less left for the following crop. The other is that the sorghums either by themselves or in their decomposition leave substances in the soil which are toxic to some crops following.

Sewell (17) found that kafir removed more fertilizing elements from the soil than did corn, but not enough to lead him to think that this was the cause of the depression.

In testing out the other theory, Sewell (17) found that leachings from pots growing kafirs, if not aerated, inhibited the growth of wheat in pots watered with the leachings more than did similar leachings from pots growing corn.

Breazeale (2) found very little if any evidence that the sorghum plant can absorb more nutrients from culture solutions than can corn. Breazeale (2) grew wheat in tap water cultures in which stubble of kafir, corn, and cowpeas, respectively, were added. In general the wheat plants in the kafir stubble culture died, while those in the corn stubble culture yellowed for a few days and then resumed normal growth, while the cowpea stubble culture had no set back. If the cultures were made up and allowed to ferment for a month before starting the wheat plants, there was no injury to those growing in the kafir cultures. From these and similar tests he was led to conclude that, "The results of these experiments indicate: First, that the injurious after-effects of sorghum is due to the presence of a toxic body formed during the decomposition of the stubble. Second, that this toxic body is shortly volatilized or decomposed."

While going through a field of barley which had been planted following milo, the writer noticed a markedly good spot about 1 foot in diameter in the otherwise poor growth. In this spot the growth was deep green, tall, and the plants had stooled profusely, while the plants outside of the spot were yellowish green, with one to three tillers per plant, and stunted. The outlines of the spot were abrupt. The spot was evidently due to the stimulation in growth resulting from the droppings of the horses preparing the land for the barley crop. To the best of the writer's knowledge, there was a good stand of milo on this spot the year before, hence the barley could not have made such good growth due to a fallow condition previous. Besides, the outlines of the spot were too well defined and abrupt. Wheat or barley planted across the border of fallow and milo will show a gradation in height of grain and vigor of growth across the border of at least 3 or 4 feet. If the assumption that this spot was good because of animal manure is correct, the "toxic body" hypothesis of Breazeale could not be used to explain this condition unless the manure can be said to have destroyed the toxic body.

Upon a more critical examination of the experiments of Breazeale, it was felt that his results could be explained or even predicted on the basis of current soil theory if one assumption was made, namely, that the stubble of the sorghums contains more sugars than did that of corn, cowpeas, or peanuts. This assumption appears reasonable since some of the sorghums at any rate have relatively high amounts of sugar in the stalks as they approach maturity. Sweet sorghums are used for the making of syrup, very little if any syrup is so made from corn stalks, so-called "corn syrup" being secured from the starch of the grain by hydrolysis.

The working hypothesis for the explanation of the injury of sorghums to crops following then becomes as follows: The sugars of the sorghums would diffuse into the soil solution after the plant had been killed and the soil wet up. The micro-organisms would use these sugars as a source of energy and would probably multiply rapidly. In so doing they would need nitrogen as a source of material for the protoplasm of the new organisms and would take it, in the form of nitrate or ammonia, from the soil solution. After the sugars and their derivatives had been completely oxidized to carbon dioxide, it would be expected that the normal nitrification processes would again be active and that the bodies of the micro-organisms which had used up the nitrates would be broken down to give nitrates again. This oxidation of the sugars would bring about a toxic condition in the soil due not to the presence of a "toxic body," but rather to the low available supply or absence of one or more essential elements.

SUGARS IN SORGHUM ROOTS

In the fall of 1926 some of the brace roots of the different sorghums and corns were taken from plants in the field and tasted. It was the belief of the writer that in nearly every case there was no doubt that there was much more sugar in the sorghum roots than in those of the corn plants. To secure some idea of the actual weight of sugar there might be in the surface foot of soil after sorghums had been grown, a block of soil 3½ feet long at right angles to the row, 1 foot deep, and 1 foot in the row was dug up and the soil carefully washed away on a screen leaving the roots exposed. These were dried and weighed. The following weights of roots were secured:

Crop	Grams
Orange County Prolific corn	122
Honey sorghum	160
Double Dwarf milo	403

Because it is nearly impossible to catch all of the fine roots and since some of the soluble material might dissolve out of the roots, these figures are probably low.

Clumps of roots of a number of the sorghums were collected and the soil allowed to dry partially and then shaken off. A small amount of soil remained. Samples were taken and run for sugars and moisture. Table 2 gives the results of these analyses computed to a dry-weight basis.

TABLE 2.—*Analyses of roots of some varieties of sorghums as grown at Davis, California, 1926.*

Variety	Glucose[a] %	Sucrose[a] %
Dwarf Blackhull kafir	2.40	11.44
White durra	5.02	7.34
Fargo milo	10.81	4.95
Double Dwarf milo	1.51	0.31
Honey sorghum	3.37	9.20
Broom corn	2.73	5.14
Sudan grass	8.10	8.28
King Phillip Indian corn	0.61	0.49

[a] Percentages on the basis of dry matter.

It will be readily seen that the corn variety analyzed is much below the varieties of sorghum in amount of sugar. From these figures and the weight of roots found above, the estimated amount of sugar present in the surface foot of soil on 1 acre would be approximately 550 pounds after honey sorghum, 35 pounds after corn, and 200 pounds after Double Dwarf milo.

SUGARS IN SORGHUMS—THE SOURCE OF THE INJURY

There is abundant evidence of the action of sugars and other carbohydrates in not only diminishing the rate of ammonification in soils but in decreasing the amount of nitrates and ammonia already present in the soil as well. Literature on this subject has been reviewed by Russell (16) and Waksman (24). As it is the purpose here to draw attention to the similarity of action between the decomposition of sorghum stubble and of carbohydrates applied to the soil, only such citations to the literature will be made as contribute to this end.

Breazeale (2) found that the injury to wheat seedlings grown in tap water cultures occurred when the seedlings were grown immediately after the sorghum stubble was added to the water; but, if decomposition was allowed to proceed for about a month before planting the wheat, no injury was noted. When the decomposition of the roots was allowed to take place near a furnace, the decomposition was completed and "a good nutrient solution" produced in less time.

Hawkins (7) observed that the injurious effect of sorghums on succeeding crops disappears in a few months after harvest.

Cole and Halstead (4) reported from field tests at Fort Hayes that spring sown barley following kafir did nearly as well as that sown after corn, but that winter wheat sown in the fall immediately after the harvest of corn and kafir was reduced in yield because of following kafir. In the rotation tests at Imperial, as reported in Table 1, wheat immediately following milo was reduced in yield to one-fifth to one-third of wheat following wheat with a summer fallow between, while on land in fallow a year between milo and the following wheat crop the yield was slightly better than for wheat following wheat. Corresponding results were secured with barley following milo.

Hutchinson (8) observed in his experiments at Rothamsted relative to the effect of carbohydrates on nitrogen fixation that conditions adverse to plant growth were brought about soon after the application of carbohydrates to the soil. This was observed not only in the early stages of the pot experiments, but to a greater degree in the field where starch and sugar were applied to different plats. The injury was greatest where the crop was sown soon after the carbohydrates were applied. Counts of bacteria run in conjunction with his experiments showed very marked increases of the bacterial flora following applications of sugar and starch. Chemical tests showed a marked decrease in the amount of nitrates and ammonia in the soil in the next few days following applications of starch and sugar. From these observations he concluded that the number of bacteria increased at the expense of readily available nitrogen in the soil.

Molasses has been used in the fertilization of cane fields in Mauritius, Leeward Islands, and Java with beneficial results. Peck (15), however, secured harmful effects sometimes by applying molasses frequently to the growing canes, though beneficial results were obtained by the application of molasses some weeks in advance of the planting of the canes.

Tempany and Giraud (19), working at Mauritius, report that the application of molasses in the furrow to growing canes may cause their death in two days. They state further that, "The most marked action of molasses applications is in relation to nitrification. After molasses is applied this process is entirely suspended and in addition nitrates primarily existing in the soil disappear, being apparently reverted to the insoluble form." They also found that soils treated with molasses containing 34.3% sucrose and 16.2% reducing sugars showed a marked increase in numbers of micro-organisms. Their conclusions seem adequately supported by experimental evidence.

Martin (14) incubated soil into which he had put wheat straw at the rate of 5 tons per acre and noted a marked decrease in nitrates. He found also by varying the amounts of straw that in general the larger the amount of straw applied the lower were the nitrates depressed. The yields of a crop planted in pots where varying amounts of straw were incorporated in the soil were depressed markedly both as to grain and straw. Where pots with varying amounts of straw were allowed to incubate for a year before planting there was practically no difference in crop yield between the check pots and those treated with straw.

Lipman, et al (13), found that dextrose depressed the yield of barley in sand cultures supplied with the essential elements, Where the amount of dextrose was increased keeping the other nutrients the same, the yield decreased. Analyses of the crops showed that with increasing applications of dextrose, a lower percentage of the nitrogen applied was recovered in the crop. Earlier tests (11, 12) had shown that carbohydrates had depressed the "ammonifying" power of the soil by pure cultures.

Doryland (5) secured a reduction in the yield of oats in sand cultures by the application of dextrose. These reductions varied from 25% to nearly 50%. By bacterial counts the numbers of bacteria were shown to have increased from 4 to 15 fold due to the application of glucose. Qualitative tests for the number of molds were also made. These seemed to show that there were many more mold organisms in the dextrose-treated cultures than in those not treated. In the dextrose cultures the molds seemed to far outnumber the bacteria. In other tests he showed that when dextrose was applied six "ammonifying" bacteria were able to compete successfully for plant food with maize seedlings grown in quartz sand under conditions which would exclude other organisms. This competition was shown by a decrease in yield of the seedlings.

From the foregoing citations it may be seen that the injury of sorghums to some crops following could be well explained or even predicted by the reaction of the micro-organisms to the sugars present in the soil, the sugars being the source of energy that allows the micro-organisms to compete with the higher plants for the elements essential for growth. In a way, only indirect evidence has been presented so far in support of the writer's hypothesis as to the injury of sorghums to succeeding crops. More direct evidence will be given below.

The Kansas Station (9) reports as follows under the subject of crop sequence of sorghums: "By four different sets of water cultures with wheat seedlings using soil solutions obtained by leaching, filtering, and centrifuging, it has been definitely determined that kafir and milo do not have a toxic effect on the soil.*** Nutrient solutions were used in conjunction with the water cultures and these indicated that kafir soil is lacking in available nitrogen. *** Soil moisture and nitrate determinations at the time of planting fall wheat showed there was less moisture and nitrates in the soil from the kafir plots than the corn plots. This may be accounted for by the fact that the kafir produces about twice as much dry matter as the corn."

In the fall of 1926 at Davis, Calif., roots of the Fargo strain of milo were dug, separated from nearly all of the soil, ground, dried, and stored to have handy as a source of sorghum roots. The roots were all from the soil within a foot of the surface. As a result of analyses for sugar these were found to contain 8.4% glucose, 6.2% sucrose, and 9.8% moisture. During the month of July 1927, incubation tests were run on varying amounts of these sorghum roots mixed with soil in pots Table 3 gives the amounts of sorghum roots mixed with the soil and the amount of nitrates present in each one as determined by the phenoldisulfonic acid method. Sugar determinations were made on a 1.2½ water extract of samples of the soils in the pots after they had been mixed with the varying amounts of sorghum roots but before the water had been added. Invertase and toluene were added to the water extract and the sugars determined as glucose after being incubated for 24 hours. The amounts of sugars as shown by analysis were only approximately what they should have been according to the alcohol extract of the roots. The cause of this discrepancy is not known. By use of the same methods no sugar was detected in the soils after having been incubated for three days with the soil wet.

TABLE 3.—*Effect of sorghum root decomposition on the amount of nitrates in 4 kg of Yolo loam soil.*[a]

	Grams dry milo roots					
	0	10	20	40	80	160
July 5.....	10.6	10.6	10.6	10.6	10.6	10.6
July 8.....	24.6	6.38	5.82	5.86	8.49	3.02
July 11....	29.2	10.6	8.6	12.4	11.6	8.3
July 14....	36.2	4.2	10.1	12.0	30.3	15.4
July 18. ..	45.6	8.45	6.82	8.90	33.5	44.5
July 25....	41.1	6.7	4.0	3.6	12.9	94.5
Aug. 1... .	44.3	7.1	5.4	3.4	13.4	112.9
Aug. 8....	50.4	10.9	6.1	2.7	8.3	107.7
Aug. 16....	43.1	12.2	12.0	3.8	7.0	127.8

[a] Analyses reported in this table were made for the writer by Mr. C. H. Timothy. Nitrates given as p.p.m. of dry soil.

By an inspection of Table 3 it will be seen that the decomposition of the sorghum roots has brought about not only a cessation of nitrification but also a reduction in the amount of nitrates present in the soil. At the end of several weeks of incubation four of the five pots showed but a small net increase, if any, in the amount of nitrates present in the soil. In the case where 160 grams of sorghum roots were mixed with 4 kilograms of soil the amount of nitrates rose to nearly three times the amount found in the check. No explanation is offered for this difference in results. However, this proportion of roots to soil is probably never attained in the field. The changes in nitrates here noted are more rapid than would probably occur in the field after sorghum harvest as these incubation studies were run in July and August, whereas the sorghum stubble decomposition in the field would take place when the soil temperatures were much lower.

If the decomposition of sorghum roots or stubble causes a reduction in the amount of nitrates in the soil and thereby hurts the crops growing on such soil, it might be expected that less nitrogen would be absorbed from the soil by the crops Breazeale (2) has some evidence on this point with tap-water cultures. One hundred plants from each of three different tap-water cultures were analyzed by him for nitrogen. The plants from the tap-water control contained 0.1316 gram of nitrogen, those from the kafir-stubble culture 0.1355 gram, and those from the corn-stubble culture 0.2520 gram. From these analyses he concluded that the kafir stubble had completely stopped the absorption of nitrogen by the plants. From the figures it may be reasonably inferred that the wheat seedlings growing in the kafir stubble culture absorbed very little if any nitrogen. Is it more reasonable to suppose that a "toxic body" or a "poison" prevented the absorption of the nitrogen, or that there was very little if any nitrogen in available form there to be absorbed?

Further evidence that the injury under these conditions is due to lack of available nitrogen is supplied by the fact that plants suffering from the "after effects of sorghum" have been benefited by the application of nitrogenous fertilizers as shown by the response in yields as given in Tables 4 and 5 below.

DISCUSSION

A toxic condition for plant growth in the soil may exist, on the one hand, from the presence in the soil of some one or more definite substances which singly or collectively are detrimental to plant growth, or, on the other hand, from the absence of one or more elements necessary for growth. It is also possible that both conditions might be operative at the same time. That there is a condition in the soil following sorghum growth which is detrimental or "toxic" to some crops seems fairly well established.

From the point of view of the presence of a toxic body, Breazeale (2) states that, "Several times the sorghum mixtures were brought to the proper stage of decomposition and the mixtures poured into a large retort and the volatile products distilled off. From a mixture that is toxic to wheat seedlings, a poisonous compound is distilled off which will kill wheat plants within a few hours. The identity of this poisonous compound or of the compounds in these toxic distillates has not been determined."

Without a more definite knowledge of the identity of these poisonous compounds it is difficult either to refute or to prove that in the soil "toxic bodies" arise from the decomposition of sorghum stubble. From such a mixture a number of compounds might be expected to result from the utilization of the sugars and other carbohydrates as a source of energy by bacteria, molds, and other micro-organisms. Thus, Lipman (10) states that "A cultural solution containing suitable mineral salts and sugar, ferments readily when inoculated with a small amount of soil. *** The cleavage products then include alcohols, organic acids and carbon dioxide. *** In general *** butyric, proprionic, acetic, formic, and lactic acid, and ethyl, propyl, butyl, and iso-butyl alcohol are common cleavage products." From a consideration of the boiling points of these compounds, undoubtedly Breazeale, in distilling his sorghum roots when fermentation was nearing completion, would secure more of the ethyl alcohol than of the others. Ethyl alcohol in higher concentrations is used for killing and preserving plant tissue. Whether Breazeale secured a concentration high enough to accomplish the killing he described is not known.

From the point of view that the toxic condition is due to lack in available form of sufficient quantities of one or more elements essential for plant growth in the soil solution, there is a fairly definite chain of evidence that is in accord with current soil theory. The different points in support of this explanation are as follows:

1. Sorghum roots contain a relatively high percentage of sugars.
2. Sugars in large enough quantities in the soil are known not only to bring nitrification practically to a standstill, but also to lessen the amount of nitrates already present in the soil within a few weeks following application.
3. The decomposition of sorghum roots represses nitrification and reduces the amount of nitrates in the soil.
4. Sorghum stubble decay may prevent absorption of nitrogen by wheat plants.
5. Plants suffering from injury due to sorghum stubble decay may be benefited by the application of fertilizers carrying nitrogen.
6. Some inoculated legumes apparently do as well, or nearly so, following sorghums as following other crops, a point which is discussed later.

If a toxic substance or poison is formed in the decomposition of the sorghum stubble, there is difficulty in explaining a number of these steps. It is hard to conceive of a situation where a toxic condition in the soil due directly to the presence of some detrimental factor may be changed and the plants growing in the soil bettered by the addition of a fertilizer unless it be assumed that the fertilizer destroys or alters the toxic substance. The toxic substance should act regardless of the fertilizer applied. From the large response in plant growth secured by the application of ammonium sulfate in one place, by sodium nitrate in another, and, if our supposition is correct with regard to the good spot in the barley field, also by manure, there is good reason to believe that the injurious after-effects of sorghum are due under the conditions of these tests not to the presence of a toxic substance or substances directly, but to the lack of available nitrogen.

It should not be supposed that the presence of sugars in the soil will result always in a toxic condition in the soil due to the absence of available nitrogen. As explained by Doryland (5), the sugars are a source of energy by the use of which the micro-organisms are enabled to compete with higher plants for the plant food elements in the soil solution. In most soils nitrogen would undoubtedly be the first element to become deficient by such competition. On the other hand, with other soils whose available supply of any essential element other than nitrogen had been depleted to a relatively low level with respect to the other essential elements, it can reasonably be expected that competition between micro-organisms and plants would rapidly deplete the available supply of this element. Crop growth might then be expected to improve markedly with the application of carriers of that element in sufficient amounts. Thus, in certain soils, sorghum injury to succeeding crops might be helped by applications of phosphate fertilizers, etc. Thus, Hutchinson (8) cites Boname as stressing the necessity for applying phosphate fertilizers on certain soils where molasses is used.

FIELD APPLICATIONS

With a logical explanation for the cause of the injury of sorghums to crops following, it is only natural that some attention should be given to the use of this explanation in overcoming or dodging the injury. So long as the theory seemed sound that the toxic condition for plant growth following sorghums was due directly to the presence of some toxic substance the exact chemical nature of which was as yet a mystery, there was not much hope for a practical field solution of the problem for the farmer. The particular "toxic bodies" or "poisonous compounds" would need to be isolated or identified and suitable means found for combating or destroying the compounds found. But with the cause explainable as the lack of some element essential for plant growth and this lack due to competition for that element between micro-organisms and the crop induced by the presence of quite large amounts of sugars and similar compounds, many points of attack appear.

REDUCTION OF AMOUNTS OF SUGARS THAT GET INTO SOIL

The less sugar there is in the soil at the time of preparing the seedbed for the crops following sorghum, the less the injury to that crop should be. Pasturing off the stubble, or burning the leaves and stalks if no animals are present to consume them, should reduce the damage. From field tests Hawkins (7) reports that, "Sorghum stalks when plowed under in sufficient quantities retard plant growth to a greater extent than do corn stalks. The root residues are not so detrimental to plant growth as the stalks."

Cole and Hallsted (4) at Fort Hayes secured a yield of wheat following kafir planted in rows double the normal distance higher than following kafir planted normally. Although the yield of kafir grain was higher in the wider spaced plats, the yield of stover was about 23% less. If the vegetative parts above ground were less per acre it might be reasonable to suppose that roots would be less in amount with the wider spacings and hence there would be less weight of sugar per acre. Thinner stands of sorghums should favor the crops following.

Another possibility of reducing the amount of sugar in the soil would be to plant varieties of sorghums low in sugars. Perhaps one of the reasons why Sudan grass and the sweet sorghums are so palatable to livestock is because of the high amount of sugars which they contain. It is reasonable to suppose that plants whose vegetative parts are high in sugar also would have roots relatively high in sugar, though this might not necessarily follow. If this should prove to be true generally, it would seem that growers of forage sorghums would have to put up with the reaction in the soil from a relatively large amount of sugars.

Growers of broom-corns and grain sorghums where the forage value of the stover is not considered of much moment should be helped by the growing of varieties whose roots are low in sugars. That there is considerable variation in the amount of sugars in different varieties of grain sorghums is shown in Table 2. A number of analyses should be made of the different varieties grown under different conditions before it is definitely said that one variety contains less sugar in its roots than another variety. It is of interest to note here that the Double Dwarf milo showed the least sugar in its roots of any analyzed. Two one-tenth acre plats in Double Dwarf milo in 1926 were planted at the same time, in the same manner, and to the same variety of barley as the Fargo milo plats reported on in Table 5 but gave very much better yields.

EARLY REMOVAL OF SUGARS AND THEIR DECOMPOSITION PRODUCTS FROM THE SOIL

Undoubtedly, if the sugars occurred in the soil solution, a heavy irrigation might displace the amount found in the surface soil to depths below to the advantage of the crops following. But the sugars get into the soil solution by diffusion from the sorghum roots after the plants have been killed. The more water there is in the soil, the more rapid and complete will be this diffusion On the other hand, more water up to the point where it does not exclude the necessary oxygen will hasten micro-biological activity in decomposing the sugars and their cleavage products. The procedure in the field which appears best is to kill the plants by suitable tillage means and then to irrigate. This should be done as soon after harvest as possible in order to allow sufficient time to elapse for complete decomposition of sugars to take place. Undoubtedly, immediately after harvest the soil temperatures are higher than they are later in the winter and decomposition of the sugars should take place more rapidly at that time. Where irrigation water is not available killing the plants and working the ground to catch the rains when they do come should prove helpful.

At Davis, Calif., during the past season a crop of Vaughn barley was quite poor when planted early in November immediately following the harvest of a plat of Fargo milo. This planting was irrigated. A field which had produced nearly as heavy a yield of the same milo and planted in late December to Sacramento barley without irrigation gave a satisfactory yield. Heavy rains occurred in October and November wetting the soil for a foot or more. The fall was quite mild until the middle of December.

APPLICATION OF FERTILIZERS TO CROPS FOLLOWING SORGHUMS

Most of the sorghums are grown in semi-arid or arid regions. In these regions nitrogen is the essential element which is most universally lacking in sufficient quantities. In the decomposition of the sorghum stubble there is a reduction in the amount of nitrogen available, hence for those crops following sorghums which require nitrogen directly from the soil increases in yield should be expected from the application of proper amounts of fertilizers carrying nitrogen. In fact results already secured in the field at the Imperial Valley Experiment Station and at Davis indicate that barley following milos gives large responses to nitrogenous fertilizers.

At the request of the writer portions of plats in the cereal rotation at the Imperial Valley Experiment Station as reported in Table 1 were treated with ammonium sulfate. Plat E of Block C had been planted to Escondido wheat and plat J to Tennessee Winter barley on Jan. 9, 1927. The lower end of each plat was divided into three equal areas of 400 square feet each. To the first of these 3 pounds of ammonium sulfate were added, the center one was left as a check,

TABLE 4.—*Effect of ammonium sulfate applications on the yield of wheat and barley following milo at the Imperial Valley Experiment Station, 1927.*[a]

Plat	Rate of application in pounds per acre	Total crop yield in pounds per acre	Threshed grain in pounds per acre
		Escondido Wheat	
E	282	3,190	1,340
E	None	2,550	1,040
E	94	2,610	1,030
		Tennessee Winter Barley	
J	282	4,440	2,030
J	None	3,825	1,240
J	94	4,125	1,660

[a] Applications were made when the plants were beginning to head on Mar. 20.

and 1 pound of ammonium sulfate was applied to the third. The fertilizer was applied on March 20 in a dry condition and the plats irrigated immediately. The grain was just heading out at this time. On the third day after the application of the ammonium sulfate it was noted that the treated sub-plats had changed in color to a very dark green. This color persisted for several days, while an abundance of new tillers started from the base. In the treated plats the maturity of the grain was prolonged several days. The sub-plats were harvested on May 16, 1927. Table 4 gives the yields of both threshed grain and total crop.

A one-tenth acre plat upon which the Fargo strain of milo had been grown in 1926 was prepared for seeding to barley by plowing one-half and disking the other. Vaughn barley was seeded with a drill on Nov. 3, 1926, and irrigated. This plat gave unmistakable evidence of unthrifty condition due to the after-effects of the previous crop of milo. Accordingly, down the center three sub-plats were laid out 20 feet long by 6 feet wide, 3 feet being on the plowed land and 3 feet on the disked land, with alleys in between. On March 19 varying quantities of nitrate of soda were applied by dissolving in water and applying with a sprinkling can. A rain of 1.95 inches occurred between March 20 and April 3. Within a week after that time the fertilized sub-plats showed a deep green color in contrast to the yellowish green of the rest of the plat. The awns were just starting to emerge from the "boot" when the fertilizer was applied. Some three weeks after the fertilizer was applied new tillers about 4 inches long were discovered coming up. These subsequently grew up nearly as high as the other heads. There was apparently very little if any elongation of the stalks which were already formed at the time the fertilizer was applied. The old stalks, even in the fertilized sub-plats, apparently matured at the same time as did the unfertilized, but the new tillers delayed the general ripening of the sub-plats for several days. Drill rows at least one removed from the

TABLE 5.—*Effect of sodium nitrate applications on the yield of Vaughn barley following Fargo milo at Davis, Calif., 1927.*

	Rate of application in pounds per acre	Yields[a]		Increase	
		Fertilized	Unfertilized[b]	Grams	%
Total crop........	600	764	380	384	101
Grain..........		291	164	135	82
Total crop........	400	580	276	304	110
Grain..........		274	135	139	103
Total crop........	200	488	326	162	50
Grain..........		226	144	82	57

[a] Yields are expressed as grams per 20-foot row spaced 6 inches apart.

[b] Average of two plats one on each side of the fertilized plat.

drill lap in planting were harvested, the total crop weighed in grams, and the crop threshed and weighed in grams. Table 5 gives the yield of total crop and threshed grain in grams per 20-foot row for a 6-inch width. At maturity the fertilized plats could be easily picked out. The boundaries were very well defined. In most cases only one drill row showed intermediate effects between the thin stand of the non-fertilized and the thick stand (brought about by tillering) of the fertilized barley. Yields from the different seedbed preparations, namely, disking and plowing, were not materially different, hence the figures are not given separately.

It is possible and even probable that higher yields might have been secured by the application of the fertilizers at an earlier stage of growth. The work of Starkey (18), who found that applications of nitrates distinctly increased the decomposition of rye straw as measured by increased evolution of CO_2 suggests that the application of nitrogenous fertilizers even before planting might hasten the decomposition of the carbohydrates in the sorghum roots to the advantage of the crop planted later.

The Kansas station (9) reports that, "Oats were grown in field soil previously cropped to corn, kafir, and milo, respectively, and fertilized with combinations of nitrogen, phosphorus, and potassium. Applications of nitrogen alone on kafir soil produced a growth of oats exceeding the untreated corn or corn soil with nitrogen."

LEGUMES FOLLOWING SORGHUMS

On soils in which nitrogen is the limiting element sorghum root decomposition because of the sugars present will depress nitrification and hence make nitrogen more of a limiting factor. The planting of legumes, either naturally or artificially inoculated, would seem to be a natural thing to do. In fact there is some evidence to support this view. Hawkins (7) reports securing satisfactory growth from field peas following sorghums but not so satisfactory from vetch. However, he attributes this to a difference in the root systems of the two plants. It is a matter of quite common experience in the Imperial Valley that alfalfa is about the only crop of those generally grown which will make a satisfactory growth following milo or other sorghums. In the rotation at the Imperial Valley Experiment Station where a crop of barley and a crop of milo and on another plat a crop of wheat and a crop of milo are grown each year, the growth of the grains has been very poor, but the growth of *Melilotus indica*, a leguminous weed in the Imperial Valley, has been very good, in fact better than on other plats because of less competition for sunlight, etc., from the poor-growing grain. At Davis during the past season apparently as satisfactory growth was secured from fenugreek (*Trigonella foenum-graecum*) following Fargo milo as following a crop of grain the previous winter in the adjoining plat, while small grains following the Fargo milo were much depressed in yield.

It may be possible by the utilization of a good leguminous crop immediately following the sorghum to change the sorghum crop to an advantage to the fertility of the soil rather than a disadvantage. If the sugars in the sorghum will hinder or entirely repress nitrification, it would force the legume bacteria to a greater activity to supply themselves with nitrogen from the air. In other words, legumes following sorghums would have to obtain a larger amount of their nitrogen from the air than those following other crops. The sugars themselves meanwhile might reasonably be expected to cause an increase in nitrogen in the soil due to *Azotobacter* activity. The total increase in nitrogen in the soil then might be expected to be greater with the sorghum-legume sequence than with most any other sequence of crops. This point will be made the subject of further investigation.

EFFECTS OF LIMITED AMOUNTS OF MOISTURE ON CROPS FOLLOWING SORGHUMS

An insufficient amount of rainfall or irrigation for the soil following the sorghum harvest may prolong the decomposition of the sugars in the stubble to the detriment of the crop following as discussed above. Aside from that reason, however, injury may be caused to the crop following because supplies of soil moisture are too limited. Under dry farming conditions the rainfall may be so meager the year following the sorghum crop as to injure greatly the small grain crop. That the sorghums may be worse than some other crops in this respect is evidenced by some data secured at Davis in 1923 and 1924.

TABLE 6.—*Relative amounts of moisture in the soil at the end of the growing season at Davis, Calif., in 1923 beneath White Yolo grain sorghum and Blackeye cowpeas grown without irrigation.*

Depth in feet	White Yolo grain sorghum moisture, M.-E. ratio[a]	Blackeye cowpeas moisture, M.-E. ratio[a]
1	0.39	0.37
2	0.49	0.53
3	0.54	0.58
4	0.58	0.64
5	0.57	0.81
6	0.55	0.91
7	0.72	1.05
8	0.77	——

[a] Moisture-equivalent run with a 30-gram sample.

During 1923 soil moisture samples were taken in a number of plats in a crop sequence study reported on elsewhere by Gilmore (6). Samples were taken by 1-foot depths with a soil tube to 6 feet or more, five holes per plat being secured, the moisture percentages determined, and the moisture-equivalents run on each sample by using 30-gram samples (22). The moisture percentage was then divided by the moisture equivalent for each sample and the moisture, moisture-equivalent ratio secured. Table 6 gives the results of such a study with Blackeye cowpeas and White Yolo, a grain sorghum.

Using the moisture, moisture-equivalent ratio as a qualitative measure of the soil moisture present, it is of interest to note that the wilting coefficient of Briggs and Shantz (3) would be expressed by the ratio 0.54 and the hydroscopic coefficient by the ratio 0.37. The figures in Table 7 show that the grain sorghum has practically exhausted the soil moisture to the wilting coefficient to a depth of 6 feet, while the cowpea crop has done so only to a depth of 3 feet. The succeeding winter's (1924) rainfall was very light (only 8.99 inches) at Davis. In the sorghum plat this had wet down between 3½ and 4 feet, the soil below that depth being apparently as dry as it was the fall before. Thus, a layer of soil approximately at the wilting point was interposed between the moist surface soil and moist deeper soil, while with the cowpea plat there was no soil that was very close to the wilting coefficient. Toward the end of the growing season, May 1924, the wheat crop following the sorghum was observed to wilt badly, while that following the cowpeas did not. Examination of the soil beneath the wheat, where sorghum had been grown, disclosed that the available moisture had been used up. Sorghums occasionally do cause injury to following crops by utilizing moisture to greater depths than may be replaced by winter rains, thereby leaving not only less moisture for the succeeding crops but a layer of soil at or below the wilting coefficient interposed between the roots of the plants and the deeper moisture. The deeper reserve moisture may therefore be cut off.

In regions where deficient rainfall is apt to follow a year of sorghum growth there would be considerable danger attending the use of a nitrogenous fertilizer. With a deficient supply of moisture in the soil a nitrogenous fertilizer would generally induce a larger vegetative growth which would need a greater amount of moisture to keep it going. This would deplete the soil moisture at an earlier stage and leave less for the latter stages of growth. Fertilization following sorghum in dry years may be more injurious to yields of grain secured than no fertilization at all.

SUMMARY

1. Observations by many experimenters have disclosed that corn is much less injurious to succeeding crops than are the various sorghums.

2. The presence of markedly good spots in the small grain crop following sorghums caused evidently by droppings from the horses preparing the seedbed cannot be adequately explained by the "toxic body" theory as the cause of the injury of sorghums to succeeding crops.

3. The observations on sorghum injury to following crops can be explained on the assumption that sorghum roots are relatively higher in sugars than other crops.

4. Analyses of the roots of six varieties of sorghums and of one variety of corn showed that the sorghum roots contained from about 65% more sugars to over 15 times as much sugar as did the corn roots analyzed.

5. Data in the literature show that the injurious after-effects of sorghums on succeeding crops largely disappear after a few months.

6. Data in the literature show that injury from the application of carbohydrates disappears after a time and that the injury is due to the competition for plant-food elements in the soil between the micro-organisms, on the one hand, and the higher plants, on the other, with resulting injury to the higher plants. In most cases this competition first depletes the supply of available nitrogen.

7. Analyses of Yolo loam soil to which varying amounts of dried milo roots had been added showed that sorghum root decay depresses nitrification and at first lowers the amount below that present in the soil at the start.

8. With the cause of sorghum injury to following crops explainable as due to the competition between micro-organisms and the crops for available plant foods resulting in one or more elements becoming limiting factors for plant growth, remedies can be suggested.

9. As sugars and possibly other carbohydrates are the primary source of the injury, every means should be used to reduce to a minimum the amount of sugar entering the soil. Means of doing this would include pasturage or removal of stalks and stubble, growing the sorghums in thinner stands, and planting varieties whose roots develop only low percentages of sugars.

10. By inducing the sorghum roots and stubble to decompose rapidly it may be possible to have the injurious period over before time to plant the following crops. This is perhaps best accomplished

by plowing to kill the sorghum plants immediately after harvest and then irrigating.

11. In most cases competition between micro-organisms and the crops following sorghums will deplete the available nitrogen supply first. Limited tests have shown marked response of barley and wheat suffering from injury caused by following a sorghum crop.

12. Naturally inoculated legumes have apparently made nearly as good if not as good growth following sorghums as following some other crops.

13. Sorghums grown without irrigation may deplete the moisture to the wilting coefficient or lower it to greater depths than do other crops. A season of low rainfall following the growth of a sorghum may not be sufficient to replenish entirely the moisture taken out by the sorghum, while it might that of some other crops. Under such a succession of conditions a crop following sorghums would have a layer of soil perhaps too dry for plant growth interposed between the top soil moistened by the rains and the supplies of moisture in the deeper soil layers. Figures and observations are given for the 1923–24 season bearing on this possibility.

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REPORT OF THE COMMITTEE ON CROPS TEACHING METHODS FOR THE AMERICAN SOCIETY OF AGRONOMY[1]

On September 20, 1926, the Committee on Crops Teaching Methods mailed to the head of the department of farm crops in each of the Land Grant Colleges in the United States, a questionnaire, calling for information relative to the Standard Introductory Course in farm crops, as given in the various institutions, and asking for an expression from the teachers of farm crops as to the advisability of attempting to standardize courses in farm crops, other than the Standard Introductory Course. Data relative to the use of the "Problem Method" in the teaching of farm crops subjects also were secured. Replies to the questionnaire were not received in time to enable the Committee to make a report at the 1926 meeting of the Society.

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[1] Presented at the annual meeting of the American Society of Agronomy, at Chicago, Ill., November 17, 1927, by J. B. Wentz for the committee comprising J. O. Morgan, Texas, *chairman;* Clyde McKee, Montana; J. E. Metzger, Maryland; G. B. Mortimer, Wisconsin; and J. B. Wentz, Iowa.

The Committee has, up to this time, received replies from 45 of the 48 institutions to which the questionnaire was mailed. Of these 45 institutions, 30 state that they have adopted the Standard Course with such modifications as their local conditions demand, while 15 institutions state that the Standard Course is not being given. Of the 30 institutions in which the Standard Course has been adopted, 12 give it in the freshman year, 12 in the sophomore year, while in 5 of the institutions the subject matter of the course has been divided into two parts and given in the freshman and sophomore or sophomore and junior years. In one instituion the course is elective to sophomores, juniors, and seniors.

In 27 of the 30 institutions, the course is required of all agricultural students. In one or two institutions where the course is required, students specializing in Landscape Art, Floriculture, or Forestry are not required to take it.

In nearly all cases the text used in connection with the Standard Course is "Field Crop Production," by Hutcheson and Wolfe. Other texts mentioned are "Forage Crops," by Piper; "Productive Farm Crops," by Montgomery; "Crop Production and Soil Management," by Cox; and crop production data worked up by the department for the students' use.

Practically all of the 30 institutions that reported the Standard Course as having been adopted have found it necessary to make certain modifications in the outline of the course, as originally recommended by the Committee. The greater number of these modifications have been made in order to place greater emphasis on local crops than is permitted by the outline. Other modifications that have been listed by one or more institutions are as follows:

One institution adds a period on the purpose of a course in field crop production.

In one institution where the course is given in the junior and senior years, more technical matter is given than is called for by the outline.

In view of more advanced courses that follow, one institution has greatly reduced the time allotted to individual crops and has increased the time devoted to Crop Ecology and the economic phase of crop production.

A few of the institutions are omitting certain topics in the outline for the reason that they are covered in other courses. The topics most frequently mentioned as being omitted are the economic and farm management phase of crop production, grain grading and marketing, and insects and diseases.

In one institution, the crop is made the unit for dicussion, rather than cultural practice. The various cultural practices are first discussed in connection with the important crop to which they apply. It is stated that some repetition of application occurs, but no more than is desirable.

CRITICISMS

The most general criticism of the Standard Course is that it is too general and that it duplicates to a serious degree the work given in other departments, notably Soils, Agricultural Economics and Farm Management. In a large number of institutions it has been found very difficult to give the work as outlined in the time allowed for the course.

The views of one of the leading institutions that has not adopted the Standard Course is expressed thus: "The Standard Course is too general, too much like a course in general agriculture. Discussing cultural practices as such without special reference to a particular crop takes away interest and is too abstract. Cultural practices can be discussed for groups of similar crops, but almost always important differences exist in application to each crop. Some repetition is pedagogically necessary. Discussion of fertilizer requirements, machinery, insects and diseases is necessary in connection with a crop, but to devote special chapters to these subjects, as such, seems out of place in this course." Another institution feels that the Standard Course should be replaced by a general plant production course —not a specialized course in Agronomy.

It has been suggested that in the outline of the course, as submitted by the Committee, the term "lectures" should be changed to "topics."

SHOULD OTHER COURSES BE STANDARDIZED?

To the question, "Should an attempt be made to standardize any courses in Farm Crops other than the Standard Introductory Course?" replies were received from 38 institutions. Of these, 12 answered "Yes," 24 answered "No," and 2 qualified their answers, one stating that, "if standardization will stimulate an attempt at gathering information in the subjects, all courses should be standardized," while the other institution felt that standardization should go "only so far as to list the things that are considered well established in agricultural science."

Those who felt that further standardization is advisable were asked to enumerate the courses that should be standardized. Practically everyone answering this question listed commercial grain and hay grading and plant breeding. Some felt that regional standardization of the main courses in field crops and forage crops is desirable, each region comprising those states in which the leading crops are more or less similar.

THE "PROBLEM METHOD" IN FARM CROPS TEACHING

Forty institutions answered the question as to whether or not the "Problem Method" is being used in connection with any of their courses in farm crops, 32 answering "Yes," and 8 answering "No." A great majority of the farm crops teachers feel that the Problem Method, if used with discretion, develops resourcefulness, and stimulates creative thinking on the part of students, and frequently gives the instructor a new point of view.

It is the general feeling that the Problem Method works well in small classes, but that it cannot satisfactorily be employed in large classes. However, the experience of many teachers has been that this method should not be used *exclusively* in any course, as this makes the course more or less monotonous and makes the instruction somewhat fragmentary. The most frequent objection to the Problem Method is that it consumes a great deal of time.

One of the leading Agricultural Colleges in which the Problem Method has been extensively employed in farm crops teaching has the following to say relative to its merits:

"On the part of our instructors, the Problem Method has produced the following results:

"1. Made each instructor search for the fundamental truths in the material he was teaching;

"2. Led to the elimination of pointless presentation of facts, when common sense tells him they cannot be retained or used by the student;

"3. Led to an appreciation of what ought to be taught in our related studies;

"4. Made the teaching of the class a pleasure, due to the eagerness with which the student attacks the problem;

"5. Has given him some basic things on which to formulate test questions which he felt the student should know and has given him confidence in ranking students on this basis.

"On the part of the student, the Problem Method has

"1. Added to and intensified his interest;

"2. Stimulated his curiosity and thought in crops and this stimulus carries over to related lines;

"3. Increased his respect for the course;

"4. Practically eliminated sleeping or inattention in class.

"The Problem Method has lifted our crops courses from a boresome line of talk and three hours of dead laboratory work, to a respected, high-prized, practical, thought-provoking study."

The Committee finds that the Problem Method is being most generally used in advanced courses, although many institutions state that it is being used, more or less, in all of their crops courses. The general consensus of opinion seems to be that the Problem Method can easily be "overdone," but that it should be resorted to with sufficient frequency to maintain interest and to fix thoroughly in the students' minds the fundamentals of crop production.

FELLOWS ELECT, 1927

FREDERIC JAMES ALWAY

Frederic James Alway is Professor of Soil Chemistry in the College of Agriculture and Chief in Soils in the Agricultural Experiment Station of the University of Minnesota. He is of Canadian birth and a product of the Canadian schools, being a graduate of the University of Toronto. He pursued post graduate work in Germany, attaining the Ph.D. degree from the University of Heidelburg.

Doctor Alway began his official career in 1898 as Professor of Chemistry at Nebraska Wesleyan. In 1908 he was made Professor of Chemistry at the University of Nebraska, in which position he served until 1913 when he was called to Minnesota to assume the duties of his present position.

In recognition of his high attainment, especially in the field of soil science and as a token of the esteem in which he is universally held, the University of Toronto has recently bestowed upon him the honorary Doctor of Science degree.

In the American Society of Agronomy, Doctor Alway served nine years, 1912-to 1920, on the committee on Soil Classifications and Mapping. He was also a member of the Committee on Fertilizers in 1921.

THEODORE ALEXANDER KIESSELBACH

Theodore Alexander Kiesselbach is Professor of Agronomy at the University of Nebraska. He is a Nebraskan by birth. He received his academic training from the University of Nebraska from which institution he holds two baccalaureate degrees, the A.B. and the B.Sc., the Master's degree of M.S.; and also the Doctor's degree of Ph.D.

Doctor Kiesselbach has remained in the service of his Alma Mater, his first official appointment being Experimental Assistant in Agronomy in 1908. From this position he has risen through the ranks of Assistant Professor, Associate Professor, finally Professor, in which capacity he has served since 1913.

Doctor Kiesselbach's best known scientific contribution arises from his extensive work on corn and its improvement.

In the American Society of Agronomy, Doctor Kiesselbach has served three years on the Committee on Standardization of Field Experiments, two years on the Committee on Cooperation with the National Research Council, and a year on the Committee on Corn Projects under the Purnell Act.

ARTHUR G. McCALL

Arthur G. McCall is the newly appointed Chief of the Division of Soils in the Bureau of Chemistry and Soils of the United States Department of Agriculture. Doctor McCall is a native of Ohio, spending his younger days on a farm in that state. He graduated from Ohio State University in 1900 and he holds the Ph.D. degree from Johns Hopkins University.

His first official appointment was in the United States Bureau of Soils in 1901. In 1904 he returned to serve his Alma Mater, beginning as Assistant Professor of Agronomy and advancing through the associate professorship to Professor of Agronomy in 1906. Ten years later he was called to the University of Maryland to become Professor of Soils and Geology, in which position he remained until assuming the responsibilities of his present office in the newly reorganized Bureau of Chemistry and Soils.

In addition to his scientific ability, McCall has displayed exceptional organizing ability which has been called into play in two outstanding services. In 1919 he served as head of the Department of Agronomy of the American Expeditionary Force, stationed at Beaune, France. In the recent International Congress of Soil Science he discharged most creditably the arduous duties of Executive Secretary.

In the American Society of Agronomy, Doctor McCall has a long record of service as a member of the committee on Varietal Nomenclature for four years, 1913 to 1917, as a member of the committee on Fertilizers in 1921, as a member of the committee on Arrangements for the Soil Congress in 1925 to 1927, as representative on the National Council of Research in 1924, as First Vice-President in 1918 to 1919, and as Second Vice-President in 1925.

RUSSEL ARTHUR OAKLEY

Russell Arthur Oakley is Senior Agronomist in charge of Forage Crops in the Bureau of Plant Industry of the United States Department of Agriculture.

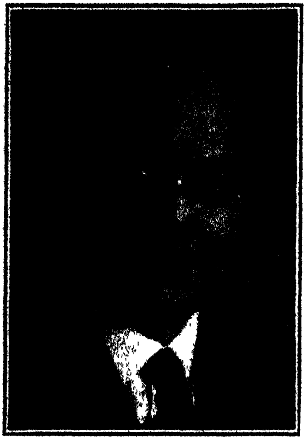
Doctor Oakley's native state is Kansas. He graduated with the degree of B.S. from the Kansas Agricultural College and he was awarded the D.Sc. degree by the Iowa State College in 1920.

Doctor Oakley is known especially for his valuable work on forage crops and we are indebted to him for extensive contributions to the literature of this subject.

Doctor Oakley has served on two important committees of the American Society of Agronomy. He was a member of the committee on Varietal Nomenclature in 1920 and 1921. For the past two years he has been Chairman of the committee on Cooperation with the National Research Council.

HERBERT KENDALL HAYES

Herbert Kendall Hayes, Professor of Plant Breeding, University of Minnesota, is a New Englander by birth, his native state being Connecticut. He is a graduate of the Massachusetts Agricultural College. His post-graduate training was taken at Harvard University from which institution he holds the M.S. and Ph.D. degrees.



Doctor Hayes began his official career as Assistant Agronomist of the Connecticut Experiment Station in 1908, and three years later he was made Plant Breeder. In 1915 he transferred his activities to the University of Minnesota, accepting the position of Associate Professor of Plant Breeding and advancing in 1918 to Professor of Plant Breeding. Doctor Hayes has made various credible contributions to the literature of plant breeding, particularly in the line of field crops. He is senior author of the well-known text book entitled "Breeding Crop Plants."

He has served the American Society of Agronomy on the committee on Varietal Nomenclature from 1916 to 1921, and since that time he has worked on the committee on Varietal Standardization. In 1926 he was made a member of the committee on Corn Projects under the Purnell Act.

AGRONOMIC AFFAIRS

MINUTES OF THE TWENTIETH ANNUAL MEETING

November 17 and 18, 1927

The meeting was called to order by the President, Dr. W. L. Burlison, at 9:30 A. M. on Thursday, November 17, at the Congress Hotel, Chicago, Ill. About 200 members and visitors registered and more than 225 were present at the different sessions.

The following special committees were appointed: *Nominating*, L. E. Call, M. F. Miller, and C. A. Mooers. *Auditing*, R. I. Throckmorton and R. J. Garber. *Resolutions*, R. W. Thatcher and C. R. Ball.

The program as arranged was presented, two sections meeting in the afternoon. The program is given on page 1148.

The annual dinner was held at 6:30 P. M. in the Congress Hotel, 135 attending. President W. L. Burlison delivered an address on "Meeting our Responsibility in Agronomic Research" which appears on pages 1049 to 1059 of this issue of the JOURNAL. The business session was then held.

OFFICERS REPORTS

R. W. Thatcher, Editor, presented his report which upon motion was accepted.

REPORT OF THE EDITOR

The JOURNAL of the Society is passing through another very successful year. Volume 19 will be nearly a duplicate of Volume 18, which was by far the best one in the history of the Society, at least so it seemed to the Editors.

Most of the credit for the editorial work on the JOURNAL for this year is due to the Assistant Editor and Business Manager who has carried almost the whole burden of the editorial service, especially since the change in professional engagement of the Editor on September 1 last. At the beginning of the year, by mutual consent the Editor was relieved of all responsibility for the actual printing of the JOURNAL and confined his editorial services to the approval of manuscripts and the necessary accompanying correspondence with authors. Since September 1, the latter service has been rendered also by Mr. Luckett, with only an occasional advisory contribution from the Editor.

In comparison with last year the first eleven issues contain 1048 pages instead of 1056 for the same issues last year. The material which is at hand and in type for the December issue will fill at least as many pages as were printed in that issue last year, so that Volume 19, as has been said, will be an almost exact duplicate of Volume 18 in size.

During the year there were received at the editorial offices a total of 140 manuscripts. This is nineteen fewer papers than were received during the preceding year, but the latter included a considerably larger proportion of short book reviews, abstracts, and notes than was received this year. The papers received are distributed among the several classes as follows: Symposium papers, 37; contributed articles, 91; book reviews, 4; notes, 8; total 140. Of these 13 were returned to their authors for one reason or another. Of the remainder, all but two, which were received after November 1, will have been published when the December issue comes from the press.

The printing of the JOURNAL has continued under the contract with W. F. Humphrey, of Geneva, N. Y., at the same rates as in former years. However, there has been a somewhat larger income from advertising than ever before and a few minor savings in operating cost have been made, so that the net cost per page has been the lowest in the history of the Journal. This is shown in the following tabulated statement covering the past five volumes.

Vol. No.	No. of Pages	Total Cost	Advertising Income	Reprints Sold	Net Cost	Cost per page
15	538	$3,221.56	$697.60	$ 94.62	$2,229.34	$4.13
16	824	4,392.79	783.97	500.40	3,106.40	3.77
17	846	4,538.19	734.65	462.03	3,341.65	3.95
18	1170	6,357.05	1,125.41	794.00	4,437.64	3.79
19[a]	952	5,284.71	1,041.46	739.29	3,503.96	3.67

[a] First ten issues.

It will be noted from these figures that the income from display advertising is slowly but steadily rising. The Assistant Editor and Business Manager reports that there are now on hand signed contracts for advertising which total $1,400 per year, with others in prospect, so that it seems to be easily possible that the net cost per page can be still further reduced next year. Stated the other way around, this means that increasing opportunities for publication of agronomic contributions will be available to members of the Society with no additional cost.

Also, it might be possible for the Journal to embark upon some enlarged program of publication service if any such additional service is really desired by the members of the Society.

The report of the Editor last year contained discussions at some length of various policies with reference to the publication of contributed articles and symposium papers in alternate issues, of acceptance of contributions only from members of the Society, etc., which need not be repeated here. No suggestions for changes in policy have come to the editors, so that it may be assumed that the present service and policies are reasonably satisfactory to the members of the Society.

Since this is the last report which the present Editor is to make to the Society, he may perhaps be pardoned if he indulges in a few reminiscences and a brief review of progress for the six years during which he has held the office.

At the outset of his services, there were turned over to him 42 unpublished manuscripts, some of which had been in the editor's hands for nearly a year, so that it appeared that the publication services of the Journal were nearly a year in arrears. The publishers were involved in a printers' strike, with the result that the issues of the Journal were being delayed from two to four months beyond their nominal date of appearance. There were nominally being issued nine numbers in each volume of the Journal, but one or more of these were usually "double" numbers so that actually six to eight issues constituted a volume. The actual number of pages printed in each volume was usually less than 400. What was worse still the funds of the Society were inadequate to pay for even this unsatisfactory Journal service and the Treasurer had to report a deficit of some $900 after payment of bills for publication of the Journal in its belated appearance, with the certainty that if publication were brought up to date the deficiency would amount to more than $2,000.

This was a rather gloomy prospect. Fortunately, however, the situation had been clearly recognized by the Society and means to remedy the financial difficulties were being carefully considered.

The printing difficulties were remedied by transferring the contract for publication of the Journal to an Albany, N. Y., firm which guaranteed prompt publication and beginning with the issue for March, 1922, each issue has appeared promptly within ten days of the middle of the month to which it was assigned. Later, a somewhat more favorable printing contract was negotiated with the present publisher at Geneva, N. Y., with some saving in expense and a very great increase in convenience to the editors.

By the end of the first year of the present Editor's service, during which 20 manuscripts were received in addition to the 40 carried over from the former year, the JOURNAL was appearing regularly on schedule time, all but three of the accumulated manuscripts either had been published in the JOURNAL or otherwise disposed of, and some advertising had been secured. There was, however, a serious deficit in the treasury. Steps to remedy this situation were taken at the annual meeting in November, 1922, by increasing the membership dues to $5.00. Also some advertising contracts had been secured. These steps served to change the financial situation for the better so rapidly that the next year the Executive Committee authorized plans for issuing 12 numbers per year of the JOURNAL.

Since then it has been easy going so far as financial and administrative problems are concerned. Our JOURNAL is one of the few, if indeed it is not the *only* technical journal of a society with relatively small membership, which has no financial support outside its own membership dues, subscriptions and advertising income, that is on a satisfactory financial and publication basis.

The earlier stages of this development were accomplished entirely through unpaid voluntary services by members of the Society. Some three years ago, however, the burden of editorial and advertising work became more than could be taken care of in this way and the Executive Committee authorized the payment of not to exceed $500 per year for editorial assistance. An assistant Editor and Business Manager was appointed and paid the modest sum of $30 per month for the first year. Later this has been increased to $750 per year and the Assistant Editor has, as has been said, taken over a large part of the editorial work as well as all responsibility for advertising contracts. This plan has worked so well that its continuance is urged, with the possibility of expansion if increased funds from advertising permit and a suitable individual arrangement can be made.

It now becomes my painful task to close this my last report as Editor by tendering my resignation to become effective with the issuance of the December issue of the JOURNAL. My new administrative duties as President of Massachusetts Agricultural College will make it impossible and probably undesirable for me to attempt to continue to give even the modicum of editorial service which I am now rendering. It is with very real regret that I sever this most pleasant and profitable relationship to the Society. In retiring, I wish to express to the officers and members of the Society my heartfelt thanks for the active support and kindly consideration which they have given to me during my six years of service as Editor of the JOURNAL.—R. W. THATCHER, *Editor*.

P. E. Brown, Treasurer, read his annual report which was received and referred to the Auditing Committee.

Professor R. I. Throckmorton reported that the Auditing Committee had examined the books and vouchers of the Treasurer and found them correct. The report was accepted.

REPORT OF THE TREASURER

I beg to submit herewith the report of the Treasurer for the year November 1, 1926, to November 1, 1927:

Balance, last report, general fund		$1,415.53
Balance, last report, Lime Assoc. fund		147.20
Total balance, last report		$1,562.73

RECEIPTS, 1927

Dues, 1927	$2,612.68	
Dues, 1927, new	603.50	
Dues, 1926	60.01	
Dues, 1928	30.00	
Subscriptions, 1927	1,011.06	
Subscriptions, 1927, new	322.40	
Subscriptions, 1926	76.76	
Subscriptions, 1928	47.50	
Advertising income	1,119.62	
Reprints sold	877.37	
Journals sold	397.75	
Total receipts	$7,158.65	$7,158.65
Total income, 1927		$8,721.38

DISBURSEMENTS, 1927

Printing the JOURNAL, reprints, etc. (11 issues Nov. 1926–Sept. 1927)	$5,896.31	
Salary Business Mgr.	687.48	
Printing programs, stationery, etc.	94.00	
Postage (Sec'y, Editor and Bus. Mgr.)	147.00	
Freight, drayage, and express	21.16	
Refunds on dues, checks returned, etc.	39.00	
Miscellaneous items (supplies, bond, expenses annual meeting, badges, etc.)	270.82	
Total disbursements	$7,155.77	$7,155.77
Balance on hand		$1,565.61
Balance, Lime Assoc. Fund	$147.20	
Balance, general fund	1,418.41	
Total balance on hand	$1,565.61	
Total income	$8,721.38	
Total disbursements	7,155.77	
Balance		$1,565.61

Respectfully submitted,
P. E. BROWN, *Treasurer.*

Approved.—R. J. GARBER and R. I. THROCKMORTON, *Auditing Committee.*

The Secretary's report was then read and upon motion was accepted.

REPORT OF THE SECRETARY

I beg to submit herewith the annual report of the Secretary for the year 1926 to 1927.

Membership.—The membership changes during the year are indicated in the following:

Membership, last report			700
Increase			
New members	107		
Reinstated	21		
Total increase	128	128	
Decrease			
Resignations	6		
Dropped N. P. D	55		
Total decrease	61	61	
Net increase		67	67
Present membership			767

Following our usual custom we perpetrated a pleasant surprise upon all members by gently but firmly reminding them, in October, that their dues were due and payable and would be thankfully received. To offset the shock of this unexpected notice, we enclosed to each member a program of the annual meeting, feeling sure that the fine lists of papers on the program and their knowledge of the fact that these papers would be published in the JOURNAL, would cause them to endure the agony of separation from five of their hard-earned simoleons--more cheerfully and resignedly. The scheme worked very well and a large proportion of the members came across promptly.

On January 1, a second notice was sent out, on February 1, a third notice, on March 15, a personal letter with a notice was dispatched and few were able to withstand the sob-story in that letter. Some hardened sinners did resist and on April 1, a second letter notified all recalcitrants that while it grieved us deeply, we were dropping their names. However, they were assured that they would be forgiven and reinstated into all the rights and privileges for the trifling sum of five iron men. Fifty-five were dropped but 21 of these reinstated, being unable to endure the prospect of more letters from us. One member admitted that he had intended to drop out but our persistence caused him to change his mind and then he said "you would make an excellent tax collector." Heaven forbid! Another man who was dropped several years ago couldn't understand why we had not sent him notices—he said "surely you don't let your members drop out so easily." No, I'll say we don't! But of course some are bound to slip away. They are poor agronomists probably— accent on poor.

A goodly number of new members was added during the year due to the activities and aid of the representatives of the Society at the various institutions. The Society owes these men a debt of gratitude and I recommend that a formal vote of thanks be extended.

REPRESENTATIVES

Prof. J. E. Metzger, Exp. Sta., College Park, Md.
Prof. J. F. Cox, Agr. College, East Lansing, Mich.

Prof. W. C. Etheridge, Univ. of Mo., Columbia, Mo.
Prof. G. W. Musgrave, Exp. Sta., New Brunswick, N. J.
Prof. R. G. Wiggans, Farm Crops Dept., Ithaca, N. Y.
Mr. J. D. Luckett, Agr. Exp. Sta., Geneva, N. Y.
Prof. F. E. Bear, O. S. U., Columbia, Ohio.
Prof. L. E. Thatcher, Wooster, Ohio.
Prof. A. L. Patrick, Exp. Sta., State College, Pa.
Prof. T. S. Buie, Clemson College, S. C.
Prof. C. A. Mooers, Univ. of Tenn., Knoxville, Tenn.
Prof. T. B. Hutcheson, Exp. Sta., Blacksburg, Va.
Prof. E. G. Schafer, State College, Pullman, Wash.
Prof. T. A. Kiesselbach, Exp. Sta., Lincoln, Nebr.
Prof. M. J. Funchess, Auburn, Ala.
Prof. R. S. Hawkins, Agronomy Dept., Tucson, Arizona.
Prof. E. J. Kinney, Exp. Sta., Lexington, Ky.
Prof. G. L. Schuster, Agronomy Dept., Newark, Del.
Prof. R. R. Childs, Agronomy Dept., Athens, Ga.
Prof. J. H. Parker, K. S. A. C., Manhattan, Kansas.
Prof. W. L. Burlison, Urbana, Illinois.
Prof. B. A. Madson, Univ. of Calif., Berkeley, Calif.
Prof. W. L. Slate, Jr., Box 1106, New Haven, Conn.
Prof. E. Van Alstine, Univ. of Vt., Burlington, Vt.
Prof. H. W. Hulbert, Univ. of Idaho, Moscow, Idaho.
Prof. S. D. Conner, Lafayette, Indiana.
Prof. A. B. Beaumont, Dept. of Soil Tech., Amherst, Mass.
Prof. A. C. Arny, Univ. of Minn., St. Paul, Minn.
Prof. Clyde McKee, Agronomy Dept., Bozeman, Mont.
Prof. O. R. Butler, Exp. Sta., Durham, N. H.
Prof. H. L. Kent, State College, New Mexico.
Prof. W. H. Darst, West Raleigh, N. C.
Prof. H. L. Walster, Dept. of Agronomy, Fargo, N. D.
Prof. H. F. Murphy, Dept. of Agronomy, Stillwater, Okla.
Prof. W. L. Powers, Oregon Agr. College, Corvallis, Ore.
Prof. B. L. Hartwell, Exp. Sta., Kingston, R. I.
Prof. J. G. Hutton, Brookings, S. D.
Prof. D. W. Pittman, Exp. Sta., Logan, Utah.
Prof. R. J. Garber, Dept. of Agronomy, Morgantown, W. Va.
Prof. E. Truog, Univ. of Wisc., Madison, Wisconsin.
Prof. A. F. Vass, Univ. of Wyo., Laramie, Wyo.
Prof. Alvin Kezer, Colo. Agr. College, Ft. Collins, Colo.
Prof. J. M. Westgate, Exp. Sta., Honolulu, Hawaii.
Prof. W. R. Dodson, Agronomy Dept., Baton Rouge, La.

The membership by states and countries is as follows:

UNITED STATES

Alabama	10	Delaware	2	Indiana	19
Arizona	7	Dist. of Col	58	Iowa	32
Arkansas	8	Florida	11	Kansas	27
California	19	Georgia	16	Kentucky	6
Colorado	7	Idaho	6	Louisiana	8
Connecticut	11	Illinois	37	Maine	4

Maryland	9	New Mexico	6	Tennessee	6
Massachusetts	7	New York	39	Texas	26
Michigan	15	North Carolina	10	Utah	10
Minnesota	17	North Dakota	20	Vermont	2
Mississippi	6	Ohio	30	Virginia	15
Missouri	19	Oklahoma	11	Washington	7
Montana	11	Oregon	6	West Virginia	7
Nebraska	20	Pennsylvania	12	Wisconsin	31
Nevada	2	Rhode Island	2	Wyoming	5
New Hampshire	2	South Carolina	9		
New Jersey	7	South Dakota	9	Total	665

FOREIGN COUNTRIES

Africa	9	Egypt	3	Jugoslavia	1
Alaska	2	England	4	Mesopotamia	1
Argentina	5	France	1	Peru	3
Autralia	3	Germany	4	Phil. Islands	3
Brazil	1	Haiti	1	Poland	1
Brit. W. Indies	1	Hawaii	8	Russia	3
Bulgaria	1	Honduras	2	Sweden	2
Canada	24	Hungary	1	Turkey	1
China	3	India	1		
Cuba	2	Italy	1	Total	102
Denmark	1	Japan	8	Total membership	767

The membership by years of admission is as follows:

1908 (Charter)	38	1915	30	1923	26
1908	10	1916	55	1924	45
1909	5	1917	24	1925	96
1910	16	1918	18	1926	92
1911	23	1919	15	1927	108
1912	18	1920	28		
1913	21	1921	42	Total	767
1914	15	1922	42		

After the members have been with us for ten years, they seem to get the habit and the record shows very few losses prior to 1921 and only one before 1917.

THE TOTAL MEMBERSHIP BY YEARS IS AS FOLLOWS:

1908—121
1909—129
1910—176
1911—236
1912—295
1913—349
1914—397
1915—471
1916—586
1917—652
1918—509
1919—473
1920—436
1921—592
1922—643*
1923—561
1924—577
1925—646
1926—700
1927—767

*In 1922 dues increased to $5.00.

The membership records are still kept alphabetically on cards, and in a loose leaf ledger, by states, and by years of election. This makes it very hard for members to escape us. After a name once gets on our books and records, it's some job for anyone to get it off. It doesn't matter where they move, we trail them and the JOURNAL trails them and once in a while we both catch up with them—and then great is the rejoicing over the return of the prodigals. We don't kill any fatted calf but that's only because we haven't any. We have trouble enough with our other livestock—keeping people from getting our goat.

Subscriptions.—Our subscription list has increased from 260 to 324, a net increase of 64. We have added 83 new subscriptions and dropped 19. We now have the largest subscription list we have ever had and the best part of it is that they are paid for. We have no exchange lists and while some libraries hate to do it—they have to *buy* our JOURNAL and the demand is such that they have to have the JOURNAL.

Journals Sold.—Many calls come in for complete sets of the JOURNAL but we cannot supply them. However, we send all that are available and realize quite a considerable income from this source. Our faithful steed hauls many a load of packages to the post office and there, after all the solemn rites are faithfully performed, we bid a fond farewell to old JOURNALS, hoping never to see them again, and paying out to Uncle Sam a large sum in postage for the privilege. And strange to relate for one whole year, we have not had a single package returned to us. This is most gratifying—but it comes too late—we lost our hair several years ago worrying over packages coming back.

Bond.—The Treasurer's bond has been renewed and we are sure that you will all be relieved to know that in spite of this fact, the Treasurer has been on the job. The Secretary vouches for the fact and will see to it that the Treasurer does not get out of the country with any of the stocks and bonds or goods and chattels of the Society. That will be easy as there "ain't none of them things nohow."

Finances.—The finances of the Society are good as appears from the Treasurer's report. We have been putting out a bigger and better JOURNAL and have been spending somewhat more for it, but we have a comfortable balance after paying for the twelve issues of the year. The income from advertising is most gratifying and we are much indebted to Mr. Luckett for his work in securing advertising for the JOURNAL.

Fellowship Nominations.—Ballots for Fellows were distributed to the Executive Committee and after several were taken the committee selected the five agronomists who will be honored this year by being elected Fellows. Diplomas have been prepared for them.

Appointments.—President Burlison appointed all the standing committees of the Society and in addition the Special Committees on the International Soil Congress and on Corn Borer Investigations were reappointed. The Committee on Fertilizer Distributing machinery was continued and Prof. Emil Truog was made chairman. The other members are F. E. Bear, J. R. Fain and S. B. Haskell.

A special committee to represent the Society at the Sessions of the Society for the Promotion of Agricultural Teaching was appointed, consisting of Dean H. L. Walster and H. D. Hughes.

A special committee was appointed to consider and recommend to the Society what action should be taken in regard to the Chilean Nitrate of Soda Educational Award. This committee consists of Prof. M. F. Miller, Chairman, A. T. Wiancko, F. J. Alway, B. L. Hartwell, T. L. Lyon, F. D. Gardner, Oswald Schreiner, C. B. Williams, and J. R. Fain.

Dr. A. G. McCall was appointed to serve as the representative of the Society on the National Research Council in place of R. A. Oakley whose health has made it impossible for him to attend the Council meetings.

A special committee to cooperate with a similar committee from the International Crop Improvement Association was appointed as follows: Prof. G. H. Cutler, Chairman, Clyde McKee, O. W. Dynes, F. P. Bussell, and R. A. Moore. The purpose of this joint committee is to attempt to develop a standard terminology for seed of improved varieties.

Meetings.—The Corn Belt Section of the Society postponed its annual meeting for one year owing to the fact that the International Congress of Soil Science and the Transcontinental Tour took place at the same time that the Section meeting was planned to be held.

The New England Section of the Society held a most successful meeting on December 3 and 4 in Boston. They report a very interesting program.

The Western Section of the Society met at Moro, Oregon, June 27-29. There was a large attendance of western agronomists and a very fine program was given.

Director Funchess was planning to have a special meeting of the Southern Agronomists, corresponding to our other sectional meetings but I guess it did not materialize. We hope it will next year.

Arrangements have been made to hold a Joint Symposium with Section O of the A.A.A.S. at the meeting in Nashville this winter on the "Corn Borer Situation."

Miscellaneous.—We were invited to have a representative at the summer meeting of the Metric Association, but no one was officially appointed and most of us were too many metres away to attend.

An invitation was extended to us to send a representative to the Berthelot Anniversary Ceremonies in Paris, but upon investigation it appeared that the American Chemical Society was quite adequately representing our interests.

In this connection I might mention that one member, in sending in his dues this fall, wrote on the bill that he would suggest that the "beautiful cover on the program be dispensed with and a fund provided to send a representative to foreign meetings." Unfortunately for this suggestion, the funds available from this source would have to be accummulated for at least 400 years before anyone would have sufficient to go aboard an ocean liner. Of course by that time air traffic may be organized and cheaper, but it is also possible that there won't be any meetings in Europe then. So we shall probably continue to have our much maligned little blue or brown or white cover on our programs. You know I wondered what that member would say to our purple badges, if he saw them.

But this is just one of many interesting letters or side lights on our office work. A number of suggestions have come in and have been referred to our Executive Committee. Method of electing officers, creation of associate members, exchanging publications, how to get our members interested, etc., are some of the topics. We have corresponded with the Farm Bureau Federation in regard to Forage Crop Investigations and General Research work in the Department of Agriculture and hope that we have been of some help.

Cities by the score, have written urging us to meet where the facilities are unexcelled, the sky is the bluest, the sun the brightest, the scenery the most gorgeous, the golf course the most wonderful, the food the most varied and tempting and the drinks—the most innocuous. The enthusiasm and activities of Chambers of Commerce is a wonderful thing!

And then the hotels—how we have been besieged with their literature, the printing companies, stenographers, badge companies, railroads, label companies, clipping bureaus, cartoon service, convention managers, advertising agencies, motor coach companies, favor companies (paper hats, etc.), and entertainment organizations too numerous to mention. We could provide music of any kind for you, entertainment of any kind for you, and we must regretfully turn them all down even the wonderful "chorus girl revues" and tell these people with a haughty expression in our letters that we are a highbrow organization whose program includes only matters of deep technical scientific interest—matters not understood by the "hoi polloi" and really "quite beyond their intelligence" and it is almost insulting to offer us entertainment. Of course we don't say just that but we often wonder what those people say when they receive our "thanks for calling their facilities to our attention." Naturally no one tells them what our members do in Chicago between programs. If any of you want to know a real place, consult the Secretary. We have had special announcements for some places it might be entertaining as well as expensive to go to.

But I might go on at length telling you of my correspondence. Suffice it to say that there is all kinds—interesting and important to foolish and negligible. But there is much of it. The President, the Editor, and the Executive Committee are inflicted with excessive correspondence from our office, but they have borne up well under the ordeal and we are deeply indebted to them for all the help they have so freely given.—P. E. BROWN, *Secretary*.

COMMITTEE REPORTS

Dr. C. R. Ball, Chairman, reported for the Committee on Terminology, part of which will be printed in a later number of the JOURNAL.

AGRONOMIC TERMINOLOGY

During the past year the Committee has given especial attention to two major problems in terminology. These are: (a) Median terms in adjectives of comparison, and (b) English plurals for Anglicized Latin nouns.

Series of three adjectives of comparison are used frequently in agronomy, and especially in genetics. At present the word "medium" is used almost exclusively as the median term, as "low," "medium," and "high" plants. This word "medium" is undesirable because it always is indefinite when used alone, and may be actually confusing when several comparisons are being made at the same time. Numerous accurate and self-explaining median terms have been selected or devised by the Committee. They are composed of the prefix "mid," followed by the root word expressing the subject of the comparison. For example, the terms "low" and "high," and also "short" and "tall," are adjectives of "height" and the proper median term is "midheight." The series then becomes "low," "midheight," "high." The median term "midhigh" should be avoided, as it represents the median point in the "high" half of the series and not the median point of the whole series. A paper by the entire Committee, embodying the arguments, conclusions, and examples of suggested median terms, has been submitted for early publication in this JOURNAL.

The chairman of the Committee has prepared an extensive discussion of the desirability of using English plurals for the thousands of Anglicized Latin nouns used so commonly in the sciences and professions. This paper has been accepted for early publication by AMERICAN SPEECH, a magazine devoted to our language, and probably will appear in the February issue. The Society generously has agreed to make reprints available to many leaders in scientific and professional groups. The paper presents 16 tables, each containing representatives of one or more groups of these nouns with their plurals formed in many different ways.

The status of the English and Latin plurals is given, as reflected by two well-known dictionaries. The author urges the universal adoption of the English plural in papers for popular readers. The equal desirability of their use in technical papers is suggested. The entire committee concurs in the recommendations.

CARLETON R. BALL, *Chairman*
HOMER L. SHANTZ
CHARLES F. SHAW

Professor S. C. Salmon made a verbal report for the Committee on Standardization of Field Experiments, no formal report being given.

Professor T. R. Stanton read the report of the Committee on Varietal Standardization which upon motion was accepted.

VARIETAL STANDARDIZATION

Crop varieties very evidently are of two different kinds, (1) the taxonomic group which may consist of types which differ widely in agronomic characteristics, (2) the agronomic group of similar genetic nature and of known breeding origin. In registering varieties on the basis of merit it appears desirable in the future to limit registration to those varieties of known origin.

In listing registered varieties of the various crops, uniformity of procedure is important. Registered varieties of each crop should be numbered consecutively, starting with No. 1 as the first registered variety of each crop.

In order to obtain action upon these suggestions, the following motions are made:

1. Only varieties or strains of known breeding history shall be eligible for registration.
2. Registration numbers shall begin with No. 1 for each crop and subsequently registered varieties shall be numbered consecutively.

H. K. HAYES, *Chairman*
T. R. STANTON
L. H. NEWMAN
L. J. STADLER
R. G. WIGGANS

No report was received from the sub-committee on registration of barley as no varieties had been submitted for registration. Prof. T. R. Stanton reported for the sub-committee on the registration of oats.

OATS REGISTRATION

During the past year seven improved varieties and strains of oats have been registered. A record of their registration has been published in the JOURNAL (Vol. 19: 1031-1037. 1927). Certificates of registration have been presented to the institutions and officials submitting the improved oats for registration.

T. R. STANTON, *Chairman*
H. H. LOVE
E. E. DOWN

Professor C. M. Woodworth reported for the sub-committee on registration of corn and the report was accepted.

CORN REGISTRATION

The sub-committee feels that there is no advantage to be had from registering open-pollinated varieties of corn. They feel further that it may be desirable to provide for registration of selfed lines of corn of proved merit or scientific interest at some time in the future. At present there are too few lines about which anything is known definitely to warrant beginning registration.

F. D. Richey (1929), *Chairman*
C. M. Woodworth (1927)
D. F. Jones (1928)

Professor J. Allen Clark presented the report of the sub-committee on registration of wheat and upon motion the first part of his report was adopted, the second part referring to the power and functions of the sub-committee was referred to the Executive Committee with power to act.

WHEAT REGISTRATION

Applications for the registration of improved wheat varieties have been requested and received by your committee. The varieties which were approved have been registered and the data published in the Journal of the Society. The applicants have been furnished with a certificate of registration.

The varieties registered this year are Nittany, Denton, Mondak, Supreme, and Albit. These names all conform to the rules of the code of nomenclature adopted by the Society. A high standard of performance has been required by your committee for the varieties registered, in comparison with the standard variety with which they were compared.

As neither the Chairman nor any member of the sub-committee for the registration of wheat varieties is a member of the Committee of Varietal Standardization, we are not in reality a sub-committee and recommend that the Society make us an independent committee. We also recommend that the chairmen of varietal registration sub-committees for the various crops be appointed to restore the former "Sub-committee on Methods of Registration."

Because of criticisms received of the certificates of registration which have been issued, our committee suggested that a more elaborate certificate be furnished. Samples of a new form have been made and referred to Mr. McCall, officer in charge of the register for the Bureau of Plant Industry, who will present them for consideration by the Society.

J. A. Clark, *Chairman*
J. H. Parker
L. R. Waldron

Professor J. B. Wentz presented the report of the Committee on Crops Teaching Methods which was accepted. This report is printed on pages 1111 to 1115 of this issue of the Journal.

Professor M. F. Miller read the report of the Committee on Soils Teaching Methods and it was accepted.

SOIL TEACHING METHODS

As several years have passed since any definite information has been obtained regarding the status of soil science teaching, the committee has decided that a certain amount of data must be collected on which to base any authentic report. As a consequence a brief questionnaire is about to be sent to all institutions of college grade in the United States and Canada where agronomic instruction is being given. At a later date a report will be made through the Journal of the American Society of Agronomy regarding the findings of the committee.

The committee is studying not only the organization of the teaching of soil science but certain specific pedagogic objectives as well. For instance, "the project" method of instruction is receiving attention, together with the possibility of utilizing a more "psychological" presentation of subject matter. The desirability of more "field instruction" is also being advanced. In this respect it will be interesting to learn to what extent "soil profile" studies are being used, especially with undergraduates. These features represent a few of the phases regarding which the committee is attempting to obtain information. It is hoped that the questionnaire, which is quite brief, will be filled out by those to whom it is addressed and returned to the chairman of the committee as soon as possible.

H. O. BUCKMAN, *Chairman*
M. F. MILLER
H. L. WALSTER

Dr. J. G. Lipman presented the report of the Special Committee on the International Congress of Soil Science and upon motion it was accepted.

FIRST INTERNATIONAL CONGRESS OF SOIL SCIENCE

The First International Congress of Soil Science was held on June 13 to 22, 1927, at the United States Chamber of Commerce, Washington, D. C. The American Society of Agronomy had authorized the appointment of a special committee which was to assume responsibility for organizing the activities of the Congress. The committee as originally appointed was instructed to enlarge its membership, if this seemed necessary. Accordingly, the following members were asked to serve on the American Organizing Committee: Oswald Schreiner, C. F. Marbut, K. F. Kellerman, A. G. McCall, and J. G. Lipman. Dr. Schreiner was elected Chairman of the committee and Dr. McCall, Executive Secretary. The Organizing Committee was enlarged by the appointment of representatives in the several states and Dr. Milton Whitney was named as Honorary Chairman of the committee. The membership of the committee is given on page 1147 of Volume 18 of the JOURNAL.

From the international point of view, the Congress was held under the auspices of the International Society of Soil Science, whose organization is shown below.

Honorary Committee

Prof. DR. L. CAYEUX	Paris
Prof. Dr. K. D. GLINKA	Lenningrad
Prof. ENG. J. KOPECKY	Praha
Sir JOHN RUSSELL	Harpenden
Prof. Dr. S. WINOGRADSKY	Paris

Executive Committee

President	
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Prof. Dr. K. O. Bjorlijkke	Aas
Prof. Dr. K. D. Glinka	Leningrad
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The program of the Congress provided for general and sectional meetings, excursions in the vicinity of Washington, the entertainment of delegates at various social functions, and rather extensive exhibits of soil maps, soil profiles, and of apparatus and equipment used by soil investigators. It is gratifying to report that President Coolidge, Secretary Jardine, and Dr. A. F. Woods, Director of Research of the United States Department of Agriculture, took a personal interest in the activities of the Congress and helped in no small way toward the ultimate success of the undertaking. There was a large attendance of both American and foreign members and delegates as well as of visitors. More than 600 persons were registered as attending the general and sectional meetings of the Congress aside from several hundred visitors who attended one or more sessions. There was outstanding interest in the educational exhibits. A report on the nature and extent of the exhibits has been prepared by Dr. Emil Truog, of the University of Wisconsin. This report will be published in the December issue of "Soil Science," together with other reports dealing with the activities of the Congress. It should be added here that several very valuable exhibits of soil and soil columns were donated by various delegations. It is hoped that these exhibits will in time be made a part of the permanent soils exhibits of the Bureau of Chemistry and Soils of the United States Department of Agriculture. Special acknowledgment is due to the delegations from Russia, Roumania, and Hungary, and to Dr. Wityn of Latvia and Dr. Stremme of Danzig for extremely valuable material donated to the Department.

All told, there were 33 countries represented at the Congress, with large delegations from Germany, Russia, the British Empire, Switzerland, and the Scandinavian Countries. Friendly contacts were established among the foreign delegates and between the foreign delegates and the American soil workers, and the foundation was laid for future professional intercourse that should serve as a stimulus to soil research in many lands. The foreign members and delegates were given an opportunity to acquaint themselves with the investigations in the field of soil science now being carried on in the United States. Thanks to the personal contacts established, they were able to arrange for the placing at their disposal of publications on soils and kindred subjects, while the American workers were able to make similar arrangements for the receipt of foreign soil literature.

By way of record, the general outline of the program is herewith given.

First Day—Monday, June 13

10:00 A. M. Registration, United States Chamber of Commerce Building.

1:45 P. M. Delegates assembled for the opening exercises.

2:00 P. M. Address by the Honorable Calvin Coolidge, President of the United States.

Response by Dr. J. G. Lipman, President of the International Society of Soil Science.

Greetings from a delegate from each continent.

Roll call of Scientific Societies.

Roll call of delegates.

Appointment of committees.

8:00 P. M. Informal reception at the Willard Hotel for delegates, members and guests.

Second Day—Tuesday, June 14

8:00 A. M. Exhibits open for inspection.

9:30 A. M. General Session—

(1) Greetings, Hon. W. M. Jardine, Secretary of Agriculture.

(2) Reports by the Presidents of the several commissions (20 minutes each).

(3) Presidential address, Dr. J. G. Lipman, New Brunswick, N. J.

(4) Address—Fertilizers and Soil Science, Mr. Chas. H. McDowell, Chicago, Illinois.

2:00 P. M. Meetings of the several commissions.

8:30 P. M. Formal reception at the Pan American Union by the Honorable W. M. Jardine, Secretary of Agriculture (by invitation).

Third Day—Wednesday, June 15

8:00 A. M. Exhibits open for inspection.

9:30 A. M. General session—Addresses:

(1) The Bureau of Soils, Its Origin and Objects, Dr. A. F. Woods, Director of Research.

(2) The Present Status of Soil Biology, Sir John Russell, Director Rothamsted Experiment Station.

(3) Determination of Soil Acidity, Prof. Dr. O. Lemmermann, Berlin, Germany.

(4) The Role of Geology in Soil Science, Prof. Dr. G. De Angelis d'Ossat, Italy.

(5) The Present Status of Soil Investigations in Japan, Dr. A. Itano, Ohara Agricultural Institute, Japan.

2:00 P. M. Meeting of the several commissions.

8:00 P. M. Formal dinner at the Willard Hotel.

Fourth Day—Thursday, June 16

7:30 A. M. Assembled at the Willard Hotel for a motor bus excursion into Western Maryland.

12:00 M. Luncheon at Hagerstown.

7:00 P. M. Dinner en route.

11:00 P. M. Arrived at Washington.

Fifth Day—Friday, June 17

8:00 A. M. Exhibits open for inspection.

9:30 A. M. General session—

(1) The Chemical Characteristics of Soil Leachings, Prof. Dr. Alexius A. J. von Sigmond, Budapest, Hungary.

(2) Trend of Land Utilization in the United States, Dr. O. E. Baker, United States Department of Agriculture.

(3) The Productive Capacity of the Globe, Dr. Albrecht Penck, University of Berlin, Germany.

(4) A Brief History of Russian Soil Science, Dr. K. D. Glinka, Leningrad, Russia.

2:00 P. M. Session devoted to a discussion of the genesis, morphology, classification and mapping of soils, to be led by the Russian delegation.

8:00 P. M. Session devoted to a discussion of chemical and physical investigations, humus, soil dynamic and agronomic investigations to be led by the Russian delegation.

Sixth Day—Saturday, June 18

8:00 A. M. Exhibits open for inspection.

9:30 A. M. Meetings of the several commissions.

2:00 P. M. Meeting of the several commissions, or Excursion to Mt. Vernon and Arlington Cemetery.

8:00 P. M. Open for concert or other entertainment.

Seventh Day—Sunday, June 19

Open for rest or attendance at Church or local excursions.

Eighth Day—Monday, June 20

8:00 A. M. Exhibits open for inspection.

9:30 A. M. Meetings of the several commissions.

2:00 P. M. Meetings of the several commissions.

8:00 P. M. Formal reception at the National Gallery of Art.

Ninth Day—Tuesday, June 21

7:00 A. M. Assembled at the Willard Hotel for motor bus trip to Baltimore. Luncheon at Baltimore.

5:00 P. M. Leave Baltimore.

7:30 P. M. Dinner at University of Maryland.

10:00 P. M. Arrived at Washington.

Tenth Day—Wednesday, June 22

8:00 A. M. Exhibits open for inspection.

9:30 A. M. Separate meeting of the several commissions.

2:00 P. M. General session for committee reports and election of officers.

10:00 P. M. Embarked on excursion train for transcontinental trip.

The field excursion which followed the meetings at Washington created an unusual opportunity both for American and foreign members and delegates to acquaint themselves with the soil and crop resources of the United States. The generosity of many organizations and individuals made it possible for the American Organizing Committee to entertain the foreign delegates as their guests during the time of the field excursion, which covered a period of one month. It was made in accordance with the itinerary given below.

Date	Place	Time		Remarks
		Arrive	Depart	
June 22	Washington, D. C.		11:00 P. M.	
June 23	Greensboro, N. C.	7:40 A. M.	10:00 P. M.	Soil examination
June 24	Knoxville, Tenn.	8:35 A. M.	8:30 P. M.	Day spent at Knoxville
June 25	Atlanta, Ga.	3:45 A. M.	8:00 A. M.	
June 25	Athens, Ga.	10:00 A. M.	5:00 P. M.	
June 25	Atlanta, Ga.	6:00 P. M.	11:00 P. M.	
June 26	Birmingham, Ala.	4:00 A. M.	4:30 A. M.	
June 26	Memphis, Tenn.	11:30 A. M.	3:00 P. M.	
June 27	Hoberg, Mo.	7:00 A. M.	10:00 A. M.	Soil examination
June 27	Carthage, Mo.	11:00 A. M.	3:30 P. M.	Soil examination
June 27	Sheldon, Mo.	4:25 P. M.	5:00 P. M.	Soil examination
June 27	Kansas City, Mo.	9:00 P. M.		Visit different points of interest
June 28	Kansas City, Mo.		11:00 P. M.	
June 28	La Crosse, Kans.	4:30 A. M.		Visit Hayes Experiment Station
June 29	La Crosse, Kans.		7:00 P. M.	
June 29	Tribune, Kans.	11:00 P. M.		
June 30	Tribune, Kans.		9:30 A. M.	Visit experiment station
June 30	Orday, Colo.	12:15 P. M.	7:00 P. M.	Trip to Rockford
June 30	Pueblo, Colo.	8:45 P. M.	9:00 P. M.	
June 30	Colo. Springs, Colo.	10:20 P. M.		
July 1	Colo. Springs, Colo.		10:00 P. M.	
July 2	Canon City, Colo.	1:30 A. M.	9:30 A. M.	Visit cherry orchards and view scenery in the Royal Gorge.
July 3	Salt Lake City, Utah.	6:30 A. M.	5:00 P. M.	Visit different points of interest
July 4	Las Vegas, Nev.	6:00 A. M.	10:15 A. M.	Soil examination
July 4	Barstow, Calif.	4:00 P. M.	6:00 P. M.	Soil examination
July 4	Riverside, Calif.	9:30 P. M.		
July 5	Riverside, Calif.		8:00 P. M.	Soil examination and visit different points of interest
July 5	Los Angeles, Calif.	9:50 P. M.		
July 6	Los Angeles, Calif.		9:30 P. M.	Visit different points of interest
July 7	Fresno, Calif.	7:00 A. M.	1:00 P. M.	Soil examination, visit points of interest.

Date	Place	Time Arrive	 Depart	Remarks
July 7	Oakland, Calif.	7:00 P. M.		Visit San Francisco and other points of interest.
July 8	Oakland, Calif.		12:30 P. M.	
July 8	Berkeley, Calif.	12:45 P. M.	1:00 P. M.	Visit different points of interest
July 9	Corvallis, Oregon	12:10 P. M.	6:30 P. M.	Visit college and experiment station
July 9	Portland, Oregon	10:00 P. M.		Visit different points of interest
July 10	Portland, Oregon		2:00 P. M.	
July 10	Seattle, Washington	7:15 P. M.	11:30 P. M.	Visit different points of interest
July 11	Vancouver, B. C.	6:00 A. M.	1:00 P. M.	Visit different points of interest
July 12	Jasper, Albt.	10:30 A. M.	9:00 P. M.	Visit Jasper National Park
July 13	Edmonton, Albt.	5:30 A. M.	7:00 P. M.	Visit university and soil examination
July 14	Saskatoon, Sask.	5:00 A. M.	10:00 A. M.	Visit university and soil examination
July 14	Regina, Sask.	3:35 P. M.	4:00 P. M.	
July 14	Indian Head	5:15 P. M.	7:00 P. M.	Soil examination
July 14	Regina, Sask.	8:30 P. M.	9:00 P. M.	
July 15	Brandon, Man.	6:00 A. M.	9:45 A. M.	Soil examination
July 15	Winnipeg, Man.	2:00 P. M.	10:00 P. M.	Visit different points of interest
July 16	Moorhead, Minn.	6:30 A. M.	10:00 P. M.	Soil examination: visit Fargo, N. D., and other points of interest.
July 17	Anoka, Minn.	7:00 A. M.	8:30 A. M.	
July 17	St. Paul, Minn.	9:30 A. M.	11:00 P. M.	Visit mills and other points of interest in St. Paul and Minneapolis
July 18	Nevada, Iowa	5:00 A. M.	2:00 P. M.	Visit Ames, Iowa
July 18	Des Moines, Iowa	3:00 P. M.	12:00 M.	Visit printing plants
July 19	Moline, Ill.	5:00 A. M.	10:30 P. M.	Visit plow works
July 20	Chicago, Ill.	3:00 A. M.		Visit stock yards and other points of interest
July 21	Chicago, Ill.	1:00 A. M.		
July 21	Lafayette, Ind.	4:15 A. M.	11:45 A. M.	Visit university and experiment station
July 21	Lebanon, Ind.	12:35 P. M.	1:30 P. M.	Soil examination
July 21	Cincinnati, Ohio	5:50 P. M.	6:30 P. M.	
July 21	Blanchester, Ohio	7:55 P. M.	10:00 P. M.	Soil examination
July 22	Washington, D. C.	1:00 P. M.		

Enthusiastic comments have come to the American Organizing Committee from individuals and from entire delegations from abroad. These comments justify the assumption that the Congress has done much toward promoting international good will and toward laying the foundation of cooperative effort in behalf of the agriculture of the entire world. Indeed, as we take stock of the work accomplished, we are led to conclude that the Congress has been the means of broadening our outlook on the entire field of soil science. There is reason to expect that soil research will receive as a result of the activities of the Congress better support from governments, educational institutions and individuals of means interested in soil research. Beyond the more immediate achievements of the Congress may be mentioned the guiding thought of those who participated in it. This guiding thought has a bearing on the large problem of food supplies and the feeding of the animal and human populations in different countries. The officers of the Second International Congress of Soil Science, which is to be held at Leningrad in 1930, are evidently determined to follow the good example set by the American Committee in developing a program that would be truly constructive in its scope and applications. The President of the Second Congress, Dr. K. D. Glinka, has already attained an enviable reputation for his contribution to soil science and may be trusted to associate with himself leaders in the field of soil science for the purpose of organizing a strong and helpful program.

The members of the American Organizing Committee are under peculiar obligation to many of the staff of the United States Department of Agriculture who gave unselfishly of their time and thought to the problems of the Congress. We feel grateful, also, to the chairmen of the various committees of the Congress, to the ladies in Washington who so graciously helped to entertain the visitors, the chambers of commerce from east to west who spared no effort to make the visiting members and delegates comfortable, the railroad officials, the agricultural colleges and universities, and to many individuals who have done much for the Congress.

By way of record, a copy of the program of the Congress is attached to this report.—J. G. LIPMAN, *Chairman.*

Dr. Lipman read the report of Dr. A. G. McCall who has been Assistant Treasurer of the Society, handling the funds of the American Organizing Committee of the Congress. Upon motion the report was received and referred to a special auditing committee, report to be made at the next annual meeting.

AMERICAN SOCIETY OF AGRONOMY IN ACCOUNT WITH THE EXECUTIVE COMMITTEE OF THE FIRST INTERNATIONAL CONGRESS OF SOIL SCIENCE

Receipts

From donors	$60,510.00
Interest	443.63
Registrations (Washington meeting)	1,597.23
Excursions (local)	938.50
Sale of abstracts	424.50
Total Receipts	$63,913.86

Disbursements

Travel	$421.51	
Transcontinental tour	33,358.25	
Entertainment	3,984.85	
Telephone and Telegraph	193.23	
Printing	2,542.36	
Office	3,968.37	
Postage	331.25	
Chamber of Commerce	1,769.73	
Translating and editing	368.25	
Payments to Foreign officers	1,735.95	
Refunds	57.14	
Miscellaneous	66.15	
Total Disbursements	$48,797.04	$48.797.04
Balance in bank as of Nov. 1		15,116.82

The above is only a rough distribution of the cost items. For example all items under "Chamber of Commerce" might be charged to office expenses. In the item "entertainment" all expenses in connection with local excursions in Maryland and Virginia are included. The item for printing programs does not cover the full cost because of the fact that about $3,500 of this cost was absorbed by the Department of State. Likewise the Department of State paid vouchers to the amount of approximately $1500 in connection with the official reception at the Pan American Union.

The total disbursements are therefore about $5,000 greater than are shown in the books of the Association.—A. G. McCall, *Assistant Treasurer, American Society of Agronomy and Executive Secretary, First International Congress of Soil Science.*

Dr. R. W. Thatcher presented a report from the Division of Biology and Agriculture of the National Research Council which upon motion was received.

NATIONAL RESEARCH COUNCIL

The National Research Council, a cooperative organization for the promotion of scientific research, is founded on the principle of representation through the national scientific societies. Taking the Division of Biology and Agriculture as an example closest to our interests, fifteen societies in both the pure and the applied fields of biology are given opportunity (1) to select someone from their respective memberships to constitute, with several members-at-large chosen by the Division as a whole, the membership of the Division; (2) to bring to the Council the research needs in their own fields which this body may be in a position to encourage; and (3) to take an active part in the general work of the Division. The history of the Division has indicated that this plan for serving the scientific groups of the country has worked out unusually well. Already a dozen or so outstanding achievements have resulted and are now operating independently as major activities in the realm of science. The work of the Council, like its membership, is a continuing process and each year as certain projects branch out to stand alone more or less, new ones arise. Consequently there is at all times a large list of active projects. Those that may be of interest especially to the members of the American Society of Agronomy are briefly reported upon below:

1. *Sulphur Fellowships.*—In 1922 the Texas Gulf Sulphur Company made available to the National Research Council a grant of $10,000 for the maintenance of eight fellowships for the following investigations:

Use of sulfur for control of diseases of the sweet potato
Use of sulfur for control of soil insects
Control of nematodes by use of sulfur
Effect of sulfur on alkali soils
Use of sulfur as a fertilizer for alfalfa or other legumes
Use of sulfur in control of potato scab

An additional grant of $7,400 was received from the same source for fellowships during 1923–24. A small balance in the appropriation permitted of some short-time fellowship studies during 1925, 1926, and 1927. It is understood that full reports of the studies pursued under these fellowships have been made annually to the American Society of Agronomy by Doctor McCall, Chairman of the Committee in charge.

2. *Other Fellowships growing out of activity of the Division.*—In addition to a number of special fellowships, funds for which have been made available at various times for the support of particular pieces of research, there has been operating since 1923 a major series of fellowships known as the National Research Fellowships in the Biological Sciences, and designed primarily for the training and development in fundamental biological science of individuals beyond the doctorate stage. These fellowships do not include within their scope agricultural research workers, except as they may be working along fundamental lines. The need for fellowships in agriculture is keenly appreciated and it is hoped that eventually support for some of this kind may be secured.

There is within the Division one special fellowship which will be of interest to the members of the American Society of Agronomy, namely the hard seed fellowship. This was maintained for three years, from 1924 to 1927, at the University of Wisconsin, with Dr. David Schmidt as the recipient, the funds being at first supplied by the American Seed Trade Association and subsequently by the Wholesale Grass Seed Dealers' Association (now known as the Farm Seed Association of North America). Beginning with the fall of 1927, the latter organization has continued the fellowship at a lesser stipend, with a graduate student working half-time at the University of Wisconsin under the direction of Doctor B. M. Duggar. A report on the work done by Doctor Schmidt is in preparation at the present time.

3. *Biological Abstracts.*—Since the establishment of the Council, this Division in particular has been concerned especially in a study of publication needs, with a view to attempting to meet some of these. As a first step in this direction was the launching of International Biological Abstracts. This abstracting journal expects to cover the scientific phases of agricultural studies, along with the whole field of biological and closely related sciences.

4. *Committee on Research Publications.*—The Division has further been concerned with a study of the needs among scientific biological journals for the publication of original research. Dr. C. E. McClung has been chairman of this committee during the past few years but inasmuch as he is out of the country now for the full year and it is felt desirable to push this study this winter, the committee is being reorganized.

5. *Rust Project.*—It may be of interest to the Society to learn that the book on North American Rusts, compiled by Doctor J. C. Arthur with the cooperation of several of his former students, Doctors C. R. Orton, F. D. Kern, F. D. Fromme,

and C. R. Bisby, is in the process of publication. John Wiley and Sons, Inc., of New York City, have agreed to publish it. This is a project in which the National Research Council has assisted to some extent by appropriating a small grant to care for a portion of the traveling expenses of the several cooperators from their respective institutions to Lafayette, Indiana, where Doctor Arthur is located.

6. *Tropical Plant Research Foundation.*—An organization developing out of one of the Division's committees and which is now independent of the National Research Council, except as the latter serves as its fiscal agent, is the Tropical Plant Research Foundation. During the several years since its establishment in 1924 the following research projects have been undertaken by the Foundation:

(a) Investigation of sugar cane production problems for the Cuba Sugar Club. Begun November 1, 1924, with an appropriation of $100,000 per annum for a five-year period.

(b) Agricultural survey of the Gomez-Meña Plantation, Cuba, for the Warner Sugar Company. March to May, 1925. Completed at a cost of $3,309.76

(c) Forestry survey of Eastern Cuba, for the United Fruit Company and the Cuba Company. October, 1925, to September, 1926. Completed at a cost of $14,000. Supplemented by a special examination of the watershed area in the vicinity of Bañes, Cuba, for the United Fruit Company, November 17 to December 16, 1926. Completed at a cost of $962.16.

(d) Survey of the sugar cane and cotton districts of western Peru, for the National Agrarian Society of Lima. January 1 to May 31, 1926. Completed at a cost of $6,000.

(e) Library research on tropical woods, for the American Society of Mechanical Engineers. Begun August, 1926; not yet completed. Appropriation, $915.

(f) Tropical forest survey, supported by the Charles Lathrop Pack Forestry Trust. Begun March 10, 1927, with an appropriation of $19,500 for three years. (Field work to be started November 1, 1927.)

7. *Crop Protection Institute.*—The work of this organization is no doubt well known to agronomists by this time. Its establishment was effected in 1920, primarily "to promote the efficient control of injurious insects, diseases and toxic substances affecting economic and ornamental plants and their products as injurious to man, domestic animals and animal products; to support and direct research upon these and other problems of a similar nature; to extend cooperation between the scientific workers and the producers of chemicals, appliances, etc., and growers and packers and shippers, and to assist in the dissemination of scientifically correct information regarding the control of injurious insects, plant diseases and toxic substances."

Projects directed by the Institute may be concerned with:

(a) The action or value of chemicals proposed for use in crop protection

(b) The value of fertilizers for the same purpose

(c) The perfecting of substances used for more successful growing of plants

(d) Determining the extent of damage done by a destructive insect or disease

(e) The treatment of mills or warehouses to eliminate damage due to insects

(f) The protection or treatment of food products, such as cereals or dried fruits

(g) Studies of by-products of manufacture to determine their possible use as insecticides or fungicides

(h) Studies of basic materials, such as copper or sulfur, to discover wider and better agricultural uses

(i) Inauguration of broad campaigns for suppression of outbreaks of destructive insects or plant diseases
(j) Establishing helpful relations between industrial organizations and scientific workers
(k) And other projects

The first of the special projects under this plan was a study of sulfur, and for a number of years a series of sulfur fellowships have been maintained by the Institute.

8. *Committees on cooperation.*—In the initial stages of the Division's development, there was greater need than at present for utilizing every means of bringing to the national societies a better understanding of the *raison d'être* and possible usefulness of the National Research Council, and to this end, in addition to the regular representation in the Division membership, committees on cooperation were suggested from the societies. For several years these committees functioned and served the purpose for which they were established, but as the Council has become better known to the societies a number of them have been dropped by their respective societies. At present but five such committees are still existant, principally because of projects started by them and not yet consummated. Among these is the committee from the American Society of Agronomy, which is also the Advisory Board of the Society. Acting under this main committee are several sub-committees, one on crops, one on soils, and one on fertilizers. The sub-committee on crops was under the leadership of Doctor Piper up to the time of his death and is now being taken charge of by Doctor C. R. Ball. The principal activity of the sub-committee on soils is the monograph which Doctor Marbut is forwarding. No recent report has been received from Doctor Lipman for the sub-committee on fertilizers. Up to a year ago there was a fourth sub-committee, namely on plant nutrition, which was in charge of the cooperative project for study of physiological salt requirements of agricultural plants.

It is interesting to note the evolution of these committees on cooperation from merely liaison bodies, as was at first conceived, into active working bodies. On behalf of the Division of Biology and Agriculture, its present officers wish to call the attention of the members of the American Society of Agronomy to the fact that the National Research Council welcomes the representation on it of the Society and that the Division is the unit through which the Society secures this representation and to whom it may bring any matters in which the Council can be of assistance. The extent to which this Society, along with the others included in this one unit, utilizes the Division organization as a means to accomplish some of its needs is the extent to which the Division itself will justify its value to the societies.—R. W. THATCHER.

Professor Emil Truog presented the report from the Special Committee on Fertilizer Distributing Machinery which was accepted. This report will be printed elsewhere in the JOURNAL. Dr F. E. Bear made a brief report on his observations abroad of interest in connection with the work of this committee.

Dean L. E. Call presented the report of the Special Committee on Corn Borer Investigations appointed by the American Society of Agronomy, the American Association of Economic Entomologists, and the American Society of Agricultural Engineers which, upon motion, was accepted.

EUROPEAN CORN BORER

The European corn borer was first discovered in the western infestation area of North America in the summer of 1920. Since then it has made a natural spread until at the present time (September, 1927) the insect occurs throughout more than 135,000 square miles of territory in the Great Lakes district of Ontario, New York, Pennsylvania, Ohio, Michigan, and Indiana. Although drastic measures are being taken to place in operation every practical agency to retard the spread and to reduce the intensity of infestation, the insect is spreading in all directions at an average rate of from 20 to 30 miles per year. In spite of this continued spread, however, the average rate of increase of the intensity of infestation has been reduced, although conditions have been favorable to such increase.

Those familiar with the habits of the corn borer, the crop losses in the principal dent corn-growing district of Ontario, and the results of the extensive studies of the borer in Central Europe, are convinced that the insect is of tremendous potentiality and ranks as one of the most alarming crop pests that has ever become established in America. Threatening, as it does, the corn crop of this country, upon which the great livestock industry depends for grain and roughage, the situation presents the possibility of a national calamity which calls for the keenest knowledge of the scientist, the wisest judgment of state and federal officials, and the closest co-operation of the growers.

The committee of entomologists, agronomists, and agricultural engineers co-operating wishes to endorse and give its hearty approval to the efforts that have been made to control the corn borer and to commend those engaged in directing the research, regulatory, and extension activities designed for its control. Especial commendation is given to the multitude of farmers who co-operated so splendidly in the clean-up campaign.

Before present control measures had been devised, or widely and completely applied, there was a rapid increase in the intensity of infestation. For example, in Essex and Kent counties, Ontario, the acreage of corn for grain was reduced about 80 per cent between 1924, when infestation had become severe, and 1927, the first year during which vigorous control measures were applied. When the best known control measures have been applied, the rate of increase in the intensity of infestation has been greatly reduced. For example, in Essex and Kent counties, Ontario, in 1927, after vigorous control measures were enforced, the infestation was reduced fully 50 per cent, although other factors may have helped. Likewise, in the United States, the rate of increase in 1927, after the compulsory clean-up, was less than one-fourth that of 1926, before a compulsory clean-up was generally enforced.

The committee reiterates its opinion that it will be impossible to eradicate the borer or even to prevent its spread to corn-growing areas not yet infested. However, it is believed that the compulsory clean-up of 1927 not only greatly reduced the rate of infestation increase but has been successful in preventing serious commercial losses, and that the expenditure of large funds for this purpose has been completely justified.

It is the desire of this committee to assist in every possible way to marshal all forces in an effort to give every possible support and encouragement to the extensive activities now under way. With this purpose in mind and after careful and complete investigation, the Committee suggests and recommends:

1. That the state and provincial agricultural experiment stations, the state departments of agriculture, and all other agencies interested in the welfare of agriculture give their support and encouragement to the federal governments toward a continuation of present policies in respect to quarantines, quarantine enforcement, and compulsory clean-up activities. Realizing, however, that

with the continued spread of the borer, it may be necessary to modify the quarantine and scouting programs within the next few years, scouting work in the area not known to be infested by the European corn borer, but apparently subject to infestations, should be continued, and the scouting work should be extended further to uninfested areas in the large corn-producing states where such areas seem particularly exposed to infestations.

2. That the co-operative projects in the infested areas now underway between agronomists and entomologists of the state experiment stations and the United States Department of Agriculture to determine the best types, varieties, and strains of corn for use under corn borer conditions be continued and expanded. The work in corn breeding has shown that marked variations exist among strains of corn in their susceptibility to corn borer infestation and in their resistance to injury. This field offers promise and is worthy of greater support. Studies to determine the best time to plant different sorts to escape commercial damage should be continued and efforts made to develop strains which may be planted at the optimum time to escape severe infestation and yet yield profitable returns.

3. That similar investigations with respect to types, time of maturing, yields, etc., be carried on in the corn states not yet infested with the European corn borer.

4. That there be made, in the area of heavy infestation, an extensive field study, involving a large number of fields, of the relation of time of planting to borer infestation, this to include correlative observations on soil types, varieties, height at the peak of moth flight, and earliness of maturity.

5. That the possibilities of the future ultimate value of parasites should be kept clearly in mind. To date 12 species have been introduced from Europe of which several have been recovered, indicating their possible establishment under our conditions. Five million of these parasites have been bred and liberated in the infested areas of the United States and Canada. It is recommended that the projects now underway and contemplated to introduce and establish parasites of the corn borer from foreign countries, be continued and enlarged as needed. These investigations should include a comprehensive study of the biology, host relationships, etc., of the introduced species in their native habitats and on this continent after they become adapted to North American conditions. This phase of the project should include biological studies in Europe and America to determine those species best adapted to present and contemplated control recommendations. Projects now underway to determine the biology, host relationships, etc., of native parasite of the corn borer should be continued.

6. That all of the major ecological phases of the corn borer problem be given special emphasis both at home and abroad. The reconnaisance ecological survey on which a good start has been made should be extended to embrace the entire corn belt and should at least cover the historical and present plant associations.

7. That since the problem of successfully combating the corn borer by mechanical processes depends upon a clear understanding and knowledge of the habits, life history, and environmental influences affecting its spread into new territory, as well as upon the limitations of corn as to seasonal, varietal, and cultural practices, more extensive studies of these factors should be made, particularly those which will assist the engineer in making specifications for improvements on present machines, as well as in the design of new and special machines for changing conditions.

8. That in view of the interdependence of machinery requirements and design, research work be undertaken co-operatively and experimental and research

programs be correlated with federal control methods and large scale field procedure.

9. The control of the corn borer by mechanical processes is of demonstrated importance and will undoubtedly continue to be so as long as the pest remains a menace to the corn crop of the country. Inasmuch as this method of control must continue until better methods can be found, we recommend that a comprehensive and vigorous research program relating to mechanical methods of crop production and commercial utilization be initiated by state and federal agencies.

10. We recommend particularly investigations with machinery in corn borer control along cultural, harvesting, and crop utilization lines. The use of rakes, burners, and other stalk and remnant disposal machinery and devices to supplant hand labor, should receive more attention.

11. That the experiments to determine the value of plowing under corn debris as a means of destroying the corn borer larvae should be extended. Such studies should include a determination of the comparative value of fall and spring plowing on different types of soil, on different dates and at different depths.

12. That since the burning of crop residues is one of the means used in the control of the European corn borer, studies on the effect of the burning of corn residues on soil productivity should be continued.

13. That consideration be given to the feasibility of determining on a large scale, in screened areas, the relative degrees of infestation and damage to be expected (1) where no effort at clean-up is made, (2) where the most practical clean-up methods are employed.

14. That the rural economists be urged to continue their studies of the costs of the various operations involved in the clean-up program and also on changes in farming systems in the areas affected.

15. That those engaged in research along agronomic and animal nutrition lines study rotations with special reference to determining the degree to which it may be possible or desirable to substitute less susceptible crops for corn in those sections where the corn borer promises to become a serious pest.

16. That investigations upon chemical insecticides, repellents, and attractants be continued, as well as those relating to the physiology of the corn borer and its chief host plants, especially corn.

17. That in one-generation areas the study of weeds and other plants than corn be continued to determine what part these may play in the future as breeding hosts of the borer, especially in districts where, owing to the severity of the infestation, corn growing may be abandoned temporarily.

18. That the state and federal extension services take every opportunity by demonstrations, exhibits, and lectures to acquaint their constituencies with the gravity of the corn borer problem, the nature of the insect and its work, and the methods of meeting the situation. The need of the cooperation of every grower in the regions adjacent to the infested areas as well as within recognized corn borer territory should be emphasized.

19. That federal and state administrative authorities be urged to make available, at frequent intervals, up-to-date information regarding the general situation and the progress of investigations in the United States, Canada, and abroad, through the medium of bulletins, circulars, and leaflets. Also where advisable, that mimeographed statements of progress be issued at frequent intervals to technical workers.

20. That the committee act as a clearing house in advancing corn borer control measures by obtaining opinions from the entomologists, agronomists, agricultural

engineers, and others, as to the lines of research and other methods which should be pursued, with special reference to needed investigations not now underway and which may have a practical application to the problems.

21. The committee recognizes that research is the basis of all progress in methods of control of the corn borer and recommends the fullest program of research along all lines offering promise of assistance and the fullest financial support for such research programs.

22. It is recommended that copies of all written reports or recommendations of the committee be made available to the Secretary of the United States Department of Agriculture and the Canadian Minister of Agriculture.

L. E. CALL, *Chairman*
W. L. BURLISON
J. F. COX
R. M. SALTER
F. D. RICHEY,
For the American Society of Agronomy

G. A. DEAN, *Chairman*
LAWSON CAESAR
J. J. DAVIS
C. J. DRAKE
D. J. CAFFREY,
For the American Association of Economic Entomologists.

H. H. MUSSELMAN, *Chairman*
E. W. LEHMANN
R. D. BARDEN,
For the American Society of Agricultural Engineers.

Dean H. L. Walster made a brief verbal report regarding the sessions of the Society for the Promotion of Agricultural Teaching, calling attention to some interesting papers presented at the meeting.

EXECUTIVE COMMITTEE

The Secretary made a report from the Executive Committee as follows: (1) It was recommended that the Society sponsor the Chilean Nitrate of Soda Nitrogen Research Award. Approved. (2) It was recommended that the subcommittee on registration of varieties be considered as actual sub-committee of the standing committee on Varietal Standardization and function as such. Referred back to the Executive Committee for action. (3) It was recommended that the Committee on Cooperation with the National Research Council be discontinued in view of the reorganization of the Division of Biology and Agriculture. Approved. (4) It was recommended that the Society elect an Elector and Advisory representation on the National Research Council. Approved. (5) It was announced that the resignation of Dr. R. W. Thatcher as Editor of the Journal had been accepted with great regret, but that Dr. Thatcher found it quite impossible to continue as Editor since accepting the Presidency of the Massachusetts Agricultural College. It was further announced that Professor J. D. Luckett had been induced to accept the Editorship and had been appointed, an Advisory Editorial Committee consisting of Dr. R. W. Thatcher, *Chairman*, Dr. C. R. Ball and Dr. T. L. Lyon being named to assist. (6) It was announced that the Executive Committee had approved of the purchase by the Society of a considerable number of reprints of an article on Terminology by Dr. C. R. Ball which will appear in American Speech.

Professor M. F. Miller presented the report of the Special Committee which had been appointed to recommend methods of precedure in handling the Chilean Nitrate of Soda Nitrogen Research Award. The report was accepted.

PLAN OF ADMINISTERING THE ANNUAL NITROGEN RESEARCH AWARD OF FIVE THOUSAND DOLLARS PROVIDED BY THE CHILEAN NITRATE OF SODA EDUCATION BUREAU AND SPONSORED BY THE AMERICAN SOCIETY OF AGRONOMY

The plan of administering the Nitrogen Research Award of the Chilean Nitrate of Soda Educational Bureau as outlined by a special committee of the American Society of Agronomy is as follows:

1. The award shall be known as the Chilean Nitrate of Soda Nitrogen Research Award.

2. The purpose of this award is to stimulate nitrogen research in relation to economic crop production.

3. Details of administering this award shall be in the hands of a committee of six, chosen from among the members of the American Society of Agronomy and known as the Nitrogen Research Award Committee.

4. This committee shall be appointed by the president of the Society elected at the annual meeting in November 1927, two members being appointed for three years, two for two years, and two for one year. Vacancies created by the automatic retirement of two members each year shall be filled by the president of the society, each incumbent being appointed for a period of three years, and a proper geographical distribution being observed in making these selections. Each incoming president of the Society shall designate the chairman of the committee for the ensuing year.

5. Awards shall be made to individuals for outstanding nitrogen research in relation to economic crop production, to be used in furthering nitrogen investigations or for professional advancement.

6. The amount of each award shall be determined by the committee in each individual case.

7. In making these awards the committee shall consider:
   (a) The work accomplished, as indicated by publications.
   (b) The facilities and funds available for the particular research project.

8. Any research worker in the United States or Canada shall be eligible to receive recognition.

9. This plan shall become operative immediately upon the acceptance of the sponsorship of the award by the Society of Agronomy and announcements of awards shall be made each year at the annual meeting of the Society.

RECOMMENDATIONS

Your committee recommends that this plan of administering the Chilean Nitrate of Soda Nitrogen Research Award be adopted by the Society and that the Nitrogen Research Award Committee be empowered to recommend such changes in the plan, from time to time, as experience and conditions indicate are desirable.

Your committee recommends further that full and immediate publicity regarding this plan be released through the proper channels.

M. F. MILLER, *Chairman*

F. J. ALWAY	J. R. FAIN
A. T. WIANCKO	T. L. LYON
B. L. HARTWELL	OSWOLD SCHREINER
F. D. GARDNER	C. B. WILLIAMS

NOMINATING

Dean L. E. Call, *Chairman*, presented the following report of the nominating committee: *Representative on the Union of Biological Sciences*, R. J. Garber, (2 years). *Elector and Advisory on the National Research Council*, C. R. Ball. *Representatives on the Council of the A.A.A.S.*, C. B. Williams and B. L. Hartwell. *Fourth Vice-President*, Dr. A. B. Beaumont. *Second Vice-President*, M. J. Funchess (to fill vacancy). *President*, A. G. McCall.

Upon motion the report was adopted and the Secretary instructed to cast the unanimous ballot of the Society for these officers. This was done and they were declared elected.

FELLOWS ELECT

The Secretary presented the names of the Fellows Elect as follows: Dr F. J. Alway, Dr. T A. Kiesselbach, Dr. R. A. Oakley, Dr. H. K. Hayes, Dr. A. G. McCall.

Dr. L. H. Smith of Illinois read a short biographical sketch of each after which diplomas were presented by President Burlison to Dr F. J Alway and Dr. T. A. Kiesselbach. Dr. Oakley, Dr Hayes and Dr. McCall were unable to be present at the meeting.

INTRODUCTION OF NEW EDITOR

President Burlison presented the new Editor of the JOURNAL, Professor J. D. Luckett of the New York Agricultural Experiment Station, to the Society.

TRIBUTE TO DR. THATCHER

Dr. C W Warburton spoke to the Society briefly and eloquently on the work and services of Dr R W. Thatcher as the Editor of its JOURNAL and on behalf of the Society, as a slight token of its esteem and appreciation, presented Dr. Thatcher with nine volumes of history and biography Dr Thatcher responded feelingly, expressing his appreciation of the gift

STANDING COMMITTEE ON FERTILIZERS

At the conclusion of the program of papers given on Friday, November 18, Dr F. E Bear moved that a standing committee on fertilizers be created, consisting of one member from each Section of the Society, to cooperate with these Sections in a national program of standardization as to usage of terms, statement of analyses, and recommendations for the various crops, due consideration being given to variations in soil and climatic factors. The motion was carried.

GREETING FROM WESTERN CANADIAN SOCIETY OF AGRONOMY

The following telegram received from L. E Kirk and J. H Ellis, Secretary of the Western Canadian Society of Agronomy, was read. "The Western Canadian Society of Agronomy extends cordial greetings to the American Society of Agronomy and hereby expresses the wish that your Annual meeting now in session may be the best in your history."

Meeting adjourned.

P. E. BROWN, *Secretary.*

PROGRAM

THURSDAY, NOVEMBER 17

8:30 A. M.

SOCIAL HOUR

9:30 A. M.

MEETING CALLED TO ORDER

President W. L. Burlison

APPOINTMENT OF COMMITTEES

SYPOSIUM: "COTTON"

Leader: M. J. Funchess

Alabama Polytechnic Institute

1. THE FRUITING HABITS OF THE COTTON PLANT

T. S. Buie

Clemson College, South Carolina

2. THE USE OF FERTILIZERS FOR COTTON

D. J. Burleson

University of Arkansas

3. THE INFLUENCE OF SPACING ON THE YIELD OF COTTON

C. A. Mooers

University of Tennessee

4. ECONOMIC COTTON PRODUCTION IN THE SOUTHEAST

F. W. Gist

Auburn, Alabama

5. COTTON PRODUCTION METHODS IN THE SOUTHWEST

A. B. Conner

College Station, Texas

SOILS SECTIONAL PROGRAM

THURSDAY, NOVEMBER 17

2:00 P. M.

SYMPOSIUM: "SOIL SOLUTION"

Leader: G. J. Bouyoucos

Michigan State College

1. THE SOIL SOLUTION FROM THE PHYSIOLOGIC STANDPOINT

B. M. Duggar

University of Wisconsin

2. THE IMPORTANCE OF SOIL TYPES ON PLANT NUTRITION

M. M. McCool

Michigan State College

3. THE RELATION BETWEEN THE TOTAL CHEMICAL COMPOSITION OF THE SOIL AND THE WATER EXTRACT

W. O. Robinson

U. S. Department of Agriculture

4. SOME EFFECTS OF FERTILIZERS ON THE NATURE OF THE SOIL SOLUTION WITH SPECIAL REFERENCE TO PHOSPHORUS
C. H. Spurway
Michigan State College
5. PLANT COMPOSITION AS A GUIDE TO THE AVAILABILITY OF SOIL NUTRIENTS
R. M. Salter
Ohio Agricultural Experiment Station

EXTENSION SECTIONAL PROGRAM

THURSDAY, NOVEMBER 17

2:00 P. M.

SYMPOSIUM: "SEED IMPROVEMENT"
Leader: C. W. Warburton
U. S. Department of Agriculture

1. THE DEVELOPMENT OF NEW VARIETIES
T. A. Kiesselbach
University of Nebraska
2. MULTIPLICATION OF IMPROVED SEED THROUGH THE SEED ASSOCIATIONS
H. C. Rather
Michigan State College
3. THE PLACE OF THE SEED TRADE IN SEED IMPROVEMENT
F. W. Kellogg
Kellogg Seed Co., Milwaukee, Wisconsin
4. DISCUSSION

THURSDAY, NOVEMBER 17

6:30 P. M.

Annual Dinner—Congress Hotel

PRESIDENT'S ADDRESS: "MEETING OUR RESPONSIBILITY IN AGRONOMIC RESEARCH"
W. L. Burlison
University of Illinois

BUSINESS MEETING
OFFICERS' REPORTS
COMMITTEE REPORTS
ELECTION OF OFFICERS
NEW BUSINESS
ANNOUNCEMENTS

FRIDAY, NOVEMBER 18

8:30 A. M.

SYMPOSIUM: "WATER RELATIONS OF PLANTS"
Leader: H. L. Shantz
University of Illinois

1. ABSORPTION OF WATER AND THE FORCES INVOLVED
   Charles A. Shull
   University of Chicago
2. CELL CONCENTRATION IN RELATION TO ABSORPTION AND TRANSPIRATION
   J. Arthur Harris
   University of Minnesota
3. WATER IN GROWTH AND ACTIVITY
   Charles F. Hottes
   University of Illinois
4. THE RELATION OF TRANSPIRATION LOSS TO ATMOSPHERIC CONDITIONS
   H. L. Shantz
   University of Illinois
5. SUMMARY. A SHORT, THOROLY SCIENTIFIC, NON-TECHNICAL STATEMENT OF OUR PRESENT VIEWS ON THE ABSORPTION, MOVEMENT AND LOSS OF MOISTURE AND ITS RELATION TO GROWTH AND ACTIVITY.
   Shull, Harris, Hottes and Shantz

FRIDAY, NOVEMBER 18

2:00 P. M.

SYPOSIUM: "FIELD EXPERIMENTS"

Leader: E. L. Worthen
Cornell University

1. THE TYPE OF PROBLEM ADAPTED TO FIELD PLOT EXPERIMENTATION
   C. F. Noll
   Pennsylvania State College
2. PLANNING THE PLOT EXPERIMENT
   H. H. Love
   Cornell University
3. THE MECHANICAL PROCEDURE OF PLOT EXPERIMENTATION
   T. A. Kiesselbach
   University of Nebraska
4. MATHEMATICS IN THE SERVICE OF AGRONOMY
   J. Arthur Harris
   University of Minnesota
5. APPLICATION OF RESULTS TO AGRICULTURAL PRACTICE
   E. L. Worthen
   Cornell University

STANDING COMMITTEES FOR 1928

President A. G. McCall has appointed the following members of the several committees of the Society for the coming year.

AGRONOMIC TERMINOLOGY

C. R. Ball, *Chairman*
Chas. F. Shaw
H. L. Shantz

STANDARDIZATION OF FIELD EXPERIMENTS

S. C. Salmon, *Chairman*
T. A. Kiesselbach
H. H. Love
M. M. McCool
C. A. Mooers

VARIETAL STANDARDIZATION

H. K. Hayes, *Chairman*
L. H. Newman
E. F. Gaines
J. H. Parker
R. G. Wiggans

SUB-COMMITTEES ON VARIETAL REGISTRATION

BARLEY

H. V. Harlan, *Chairman* (1929)
R. G. Wiggans (1928)
L. H. Newman (1930)

CORN

F. D. Richey, *Chiarman* (1929)
C. M. Woodworth (1930)
D. F. Jones (1928)

OATS

T. R. Stanton, *Chairman* (1929)
H. H. Love (1928)
E. F. Gaines (1930)

WHEAT

J. Allen Clark, *Chairman* (1929)
L. R. Waldron (1928)
J. H. Parker (1930)

CROPS TEACHING METHODS

J. O. Morgan, *Chairman*
Clyde McKee
J. B. Wentz

SOILS TEACHING METHODS

H. O. Buckman *Chairman*
M. F. Miller
H. L. Walster

CHILEAN NITRATE OF SODA NITROGEN RESEARCH AWARD

M. F. Miller, *Chairman* (1928)
Charles F. Shaw (1928)
R. R. McKibbin (1929)
Oswald Schreiner (1929)
R. W. Thatcher (1930)
C. B. Williams (1930)

COMMITTEE ON FERTILIZERS

F. E. Bear, *Chairman*
A. B. Beaumont
John W. Gilmore
J. C. Pridmore

NEWS ITEMS

DIRECTOR H. G. KNIGHT of the West Virginia Agricultural Experiment Station and also Dean of the College of Agriculture resigned on October 1 to become Chief of the new Bureau of Chemistry and Soils of the United States Department of Agriculture.

A. S. HECK, Assistant Professor of Soils at Washington State College, has been granted an additional year's leave of absence for graduate study at the University of Wisconsin.

ROSCOE E. BELL, who has been teaching fellow in the Department of Soils at Washington State College, on September 1 was appointed instructor in soils,

A. G. MCCALL has resigned as head of the Department of Soils and Geology in charge of soil investigations at the University of Maryland Agricultural Experiment Station in order to become head of the Division of Soils in the new Bureau of Chemistry and Soils in the United States Department of Agriculture.

GEORGE L. SCHUSTER has been granted leave of absence from his duties as professor of agronomy and agronomist at the Delaware University and Experiment Station in order to take up graduate work at Cornell University.

CLAUDE E. PHILLIPS and O. A. Pope have been appointed assistant agronomists at the Delaware Agricultural Experiment Station.

J. M. GRAHAM has resigned as assistant agronomist at the Delaware Agricultural Experiment Station.

FRED H. HULL, Assistant in the Department of Genetics, Iowa State College, has been appointed Assistant Agronomist at the Florida Experiment Station and will be engaged primarily on corn breeding problems.

C. R. ENLOW, Assistant Professor of Agronomy at the Kansas Agricultural College, has been appointed Special Agent for the Office of Forage Crop Investigations, U. S. Department of Agriculture, and has been detailed to the Florida Experiment Station to work in cooperation with the Agronomy Department on pasture and forage crop problems.

A. S. LAIRD, who recently received his master's degree at the University of Florida, has been appointed Assistant Agronomist at the Florida Experiment Station.

J. H. HUNTER, a graduate of Clemson Agricultural College and the University of Kentucky, has been appointed Assistant Agronomist at the Florida Experiment Station and detailed for duty at the Everglades Branch Experiment Station at Belle Glade, Fla.

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